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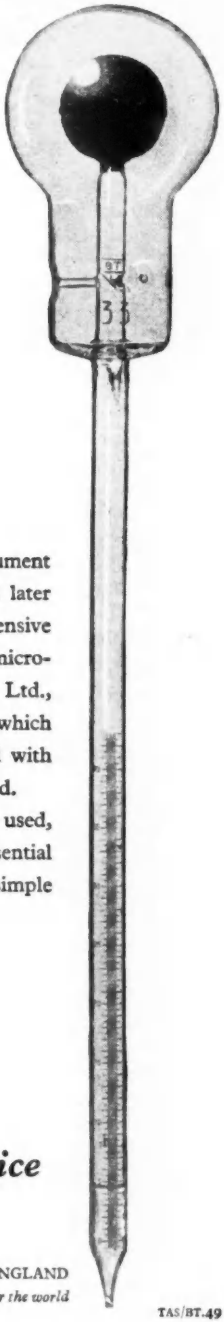

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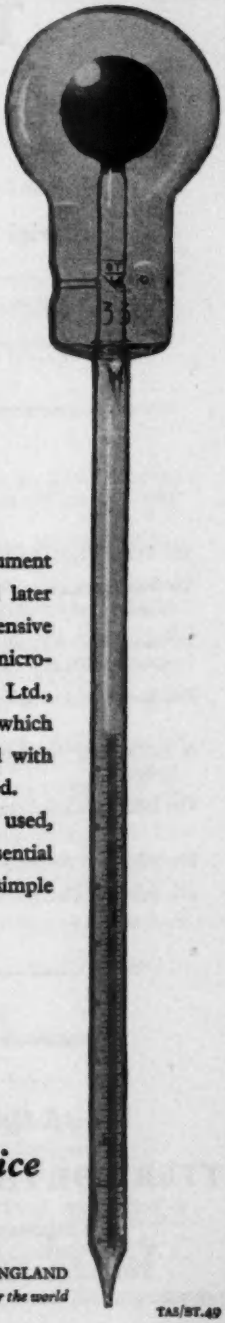

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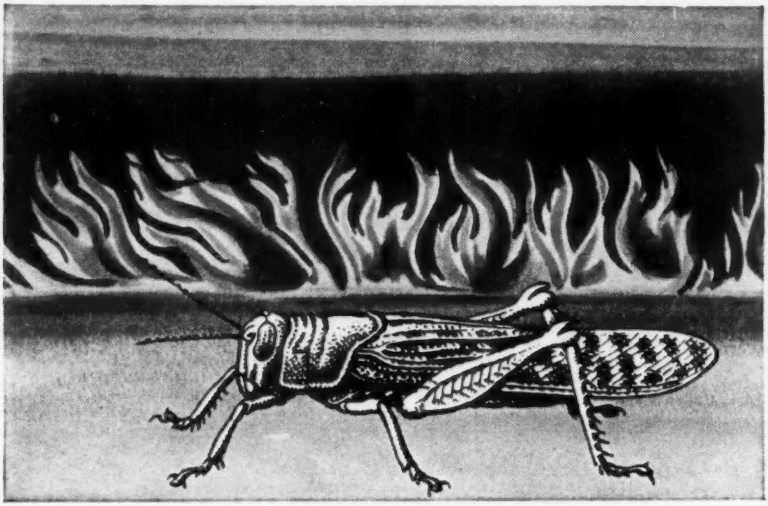

Flame in the far desert

Today, a spreading yellow stain: advancing, enlarging, flowing together, smouldering under the desert sun. Tomorrow—if not extinguished—a searing, consuming flame, flying on the breast of the wind, fiercer by far than the ever-burning fires of Baba Gurgur in Irak, a plague borne on a thousand million wings.

From time immemorial, the Desert Locust (*Schistocerca gregaria* FORSK.) has scourged, year by year, a vast sweep of Africa and Asia. Through bitter centuries, men of many tongues have watched helplessly and without hope as the greenness was stripped from the earth.

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MANURING EXPERIMENTS ON FLAX

G. W. COOKE AND R. G. WARREN

(*Rothamsted Experimental Station, Harpenden, Herts.*)

Summary

Fifty experiments on flax were carried out in 1940–5 to examine the effects of manuring on yield and quality of the crop. Yields of total produce and deseeded straw were measured quite precisely but processing introduced irregularities and yield data for scutched flax were much less accurate.

Nitrogen increased yield of total crop, on average of all experiments, by about 5 per cent., and yield of green-scutched flax by about 2 per cent. Phosphorus increased both total yield and yield of processed flax by less than 2 per cent. Potassium also had only small effects; on average it increased yield of total crop by 1·5 per cent. and yield of green-scutched flax by 4 per cent. In some experiments the produce was both green-scutched by a dry process and also scutched after retting. The effects of fertilizers on yield of processed flax depended on the method of processing used. Nitrogen increased the yield of retted-scutched flax by about 7 per cent., and potassium by about 2 per cent.; phosphorus had only a small effect.

Agricultural salt consistently lowered yields of total crop and of green-scutched flax, also it reduced the average percentage of scutched flax recovered from the straw.

In experiments carried out on land ploughed from grass the average increase in yield given by ammonium sulphate was about half the increase on land where arable crops had been grown for three or more years. On soils with more than 0·3 per cent. total N the response to the fertilizer nitrogen was one-third of that on soils lower in nitrogen. Determinations of citric-acid-soluble soil phosphorus and acetic-acid-soluble soil potassium were of considerable value in picking out centres where significant and profitable responses were given by phosphorus and potassium fertilizers.

Manuring of flax is justified only when there is evidence from chemical analysis, or from experience, that the soil is deficient in one or more of the major plant nutrients.

THE acreage of flax in Britain increased rapidly during the 1939–45 war from 15,000 in 1940 to 51,000 in 1944. At the beginning of the war there was very little information on which to base recommendations for manuring of flax in England, Wales, or Scotland. The crop had been grown for many years in Ireland and the results of 141 field experiments were published by the Department of Agriculture for Ireland [1] between 1903 and 1919; they have been summarized by Boyd (private communication). In the Irish experiments flax responded everywhere to dressings of potassium fertilizers: there were responses to ammonium sulphate in two-thirds of the experiments and to phosphorus fertilizers at only one-third of the centres. As it was not certain that the results of the Irish work would apply in Great Britain the series of field experiments here described was carried out to test the effect of the principal fertilizers on the yield and quality of flax. The work was planned at conferences arranged by the Ministry of Agriculture and the Ministry of Supply. Most of the experiments were carried out on ordinary commercial farms by advisory soil chemists and by members of the

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staffs of agricultural colleges and departments of agriculture. The investigation was co-ordinated by the Rothamsted Experimental Station, which was also responsible for statistical analyses of the data, for chemical analyses of the soils, and for preparing reports on the experiments. Acknowledgement to those who took part in the work is made at the end of this paper.

The produce of the experiments was processed at H.M. Norfolk Flax Establishment, Flitcham Abbey, King's Lynn. The traditional method of extracting fibre from flax is to remove the seed first and then to immerse the straw in water for retting. During the retting stage pectic substances which bind the fibres together are decomposed by fermentation. After drying the retted straw, it is 'scutched' to separate the fibre from the stem. As it was intended that most of the flax grown in England should be deseeded and then treated mechanically by a 'green scutching' process which obviates the need for retting, the produce of the experiments in the first three years was treated in this way. In 1943 and 1944 crops from most of the experiments were processed by green scutching and also by retting followed by scutching, while in 1945 the crops were treated only by retting followed by scutching. In a few of the experiments it was not possible to process the produce; these have been excluded from the general summary presented here, as also have data from a few experiments which gave poor average yields.

Descriptions of the Experiments

The fertilizers tested in all the experiments were ammonium sulphate, superphosphate, and muriate of potash. A few preliminary experiments in 1940 tested all combinations of:

0·0, 0·2, and 0·4 cwt. N per acre
0·0, 0·4, and 0·8 cwt. P_2O_5 per acre
0·0, 0·6, and 1·2 cwt. K_2O per acre.

The twenty-seven treatments were arranged in the usual $3 \times 3 \times 3$ design having three blocks each of nine plots. Three experiments were taken through to the processing stage and yields of green-scutched flax were obtained. Data presented here from the 1940 experiments are averages of the responses to the two rates of fertilizer application.

The experiments carried out in 1941, 1942, and 1943 were of a uniform pattern and tested nitrogen, phosphate, and potash, and also agricultural salt, each at one rate of application. (As salt had been outstandingly successful in a parallel series of experiments on sugar-beet and had given larger responses than potassium fertilizer, it was included in the flax experiments to see whether home-produced sodium chloride could improve yields of flax and if it could be substituted for potash, supplies of which were seriously restricted during the war period.) All combinations of the following dressings per acre were tested:

0·0 and 0·2 cwt. N
0·0 and 0·6 cwt. P_2O_5
0·0 and 0·9 cwt. K_2O
0·0 and 3·0 cwt. of agricultural salt.

The sixteen treatments were laid out in four blocks each of eight plots by confounding the four-factor interaction. Agricultural salt decreased total yields at most centres in each of the 3 years and also reduced the amount of flax extracted; this treatment was therefore abandoned. In 1944 and 1945 the experiments tested all combinations of the presence and absence of 0·2 cwt. N, 0·6 cwt. P_2O_5, and 0·9 cwt. K_2O per acre, the eight treatments being laid out in each of four randomized blocks.

TABLE 1. *Standard Errors per Plot in Flax Experiments expressed as Percentages of the General Mean values*

	No. of experiments	*Total crop*	*Deseeded straw*	*Seed*	*Scutched flax*
		Mean standard error for year			
					Green scutching
1941 . .	7	6·7	7·2	12·5	15·1
1942 . .	11	10·8	10·5	23·0	14·6
1943 . .	11	7·3	7·8	13·2	17·5
1944 . .	7	8·3	8·7	12·4	25·4
1941–4 .	36	8·4	8·7	15·9	17·7
					Retting and scutching
1944 . .	9	9·4	9·6	14·6	18·5
1945 . .	9	8·5	8·7	..	21·3

Distribution of Individual Values for All Experiments in 1940–4

Per cent. standard error	*Numbers of experiments*			
to 5·0	5	7	0	0
5·1–10·0	23	20	8	2
10·1–15·0	6	8	10	11
15·1–20·0	3	2	6	15
20·1–25·0	0	0	2	3
Over 25	0	0	5	6

Over the six years fifty experiments provided yields of total crop and scutched flax. The detailed results of all experiments for each of the factors measured are stated fully in a mimeographed Report, of which a limited number of copies are available for distribution; the results at individual centres are not discussed here. The use of two methods of processing in 1943 and 1944, and of retting alone in 1945, complicates the presentation of yields of scutched flax. Separate means are given for all comparable experiments providing yields of green-scutched flax and of retted-scutched flax. In the experiments of 1943 and 1944 where both processes were used, the two sets of data are strictly comparable and they have been used to compare the effects of method of processing on fertilizer responses.

Precision of the Experiments

Standard errors of both total crop yields and of processed flax yields

TABLE 2. *Mean Yields and Effects of Fertilizers in Experiments on Flax carried out from 1940 to 1945 (all similarly treated experiments in each year have been averaged)*

	No. of experiments	*Mean yield*	*Effect of* N	P	K
Total crop (cwt./acre)					
1940	3	44·6	4·4	−1·3	1·3
1941	6	49·9	1·9	0·8	−0·5
1942	11	41·7	2·6	−0·1	0·7
1943	11	49·3	2·0	1·5	0·4
1944	9	41·8	3·7	0·6	2·1
1945	10	53·2	2·0	1·9	0·4
All years	50	46·8	2·6	0·8	0·7
Deseeded straw (cwt./acre)					
1940	3	25·6	2·4	−1·7	1·9
1941	6	33·3	1·1	0·4	−0·2
1942	11	28·8	1·9	0·1	0·1
1943	11	34·1	1·4	1·3	0·4
1944	9	29·8	2·4	0·2	1·3
1945	10	35·5	0·8	1·0	0·6
All years	50	31·8	1·6	0·5	0·6
Seed (cwt./acre)					
1941	6	7·06	0·25	−0·11	−0·25
1942	11	4·55	0·20	−0·08	0·19
1943	8	4·31	0·20	0·13	0·06
1944	9	4·78	0·27	0·11	0·26
All years	34	5·00	0·23	0·01	0·10
Green-scutched flax (cwt./acre)					
1940	3	3·61	−0·32	−0·45	0·74
1941	6	5·06	−0·04	0·00	−0·02
1942	11	5·86	0·25	0·07	0·14
1943	11	5·54	−0·09	0·24	0·16
1944	7	4·87	0·42	0·17	0·41
All years	38	5·28	0·09	0·09	0·22
Retted-scutched flax (cwt./acre)					
1943	9	4·34	0·40	0·09	0·05
1944	9	4·14	0·34	0·10	0·18
1945	9	4·62	0·13	−0·03	0·00
All years	27	4·37	0·29	0·05	0·08
Green-scutched flax as percentage of deseeded straw					
1940	3	14·2	−1·9	−1·5	1·7
1941	6	17·1	−0·2	0·1	−0·4
1942	11	19·6	−0·2	0·1	0·2
1943	11	16·2	−0·9	0·2	0·4
1944	7	14·4	0·2	0·5	0·5
All years	38	16·8	−0·5	0·1	0·4
Retted-scutched flax as percentage of deseeded straw					
1943	9	12·9	0·1	−0·1	0·4
1944	9	13·1	0·0	0·1	0·1
1945	9	12·5	−0·3	−0·3	−0·3
All years	27	12·8	−0·1	−0·1	0·1

are summarized in Table 1; they indicate the degrees of accuracy attained in yield comparisons at the various stages. For yields of both total crop and deseeded straw the standard errors per plot averaged about 8 per cent. of the general mean yields for the years 1941, 1943, 1944, and 1945; this compares favourably with the values generally obtained in field experiments on cereals and root crops. In each of these years the yields of processed flax had standard errors (expressed as percentages of the mean yield) which were on average at least twice as great as those obtained for the total crop. In 1942 the yields of total crop and of deseeded straw had higher standard errors while the yields of green-scutched flax had somewhat lower errors than in other years. The greater part of the experimental variance in green-scutched or retted-scutched flax yields arose during the factory processing and only a smaller part was due to inevitable irregularities of soil and other conditions in the field. The extra error introduced during factory processing meant that sizeable differences in yield could arise quite frequently by chance; it has therefore been difficult to draw precise conclusions on the effects of fertilizers on yield of processed flax.

Effects of Nitrogen, Phosphorus, and Potassium Fertilizers on Yields of Flax

A summary of mean yields and of the estimated effects of ammonium sulphate, superphosphate, and muriate of potash is given in Table 2 for each of the important measurements made in the experiments; averages for all comparable experiments in each year are stated. The data are examined further in Table 3 by stating the numbers of estimated positive and negative effects and the numbers of significant effects of the three fertilizers.

Total crop

On average of fifty experiments nitrogen increased yield by about 5 per cent.; increases were obtained in four-fifths of the individual experiments and in half of these the increases were significant; the yield of total crop was not depressed significantly by nitrogen at any centre. With both phosphorus and potassium average increases in yield of less than 2 per cent. were obtained. Increased yields were obtained with phosphorus in three-fifths of the experiments but these were significant at only seven centres; there were no significant decreases in yield due to phosphorus. Increased yields were also obtained with potassium in three-fifths of all the experiments; significant increases were recorded at six centres and significant decreases at two.

Deseeded Straw

Average yield of deseeded straw comprised about two-thirds of the average total crop yield. The overall estimated effects of fertilizers and the frequencies of positive and negative effects at individual centres were similar to those recorded for the total crop.

Seed

Measurements of seed yields were much less precise than those of total crop or of straw (Table 1). Average yields increased by nearly 5 per cent. with nitrogen and increases were obtained at two-thirds of the centres where seed was weighed; the increases were significant in only

TABLE 3. *Numbers of Positive and Negative Effects of Nitrogen, Phosphorus, and Potassium on Flax Yields and the Numbers of Significant Effects* (P = 0·05 or less)

	Total crop	*Seed*	*Deseeded straw*	*Green-scutched flax*	*Retted-scutched flax*
Number of experiments	50	34	50	38	27
Numbers of effects of nitrogen					
positive . .	42	24	41	22	22
negative . .	7	10	8	16	5
Significant effects:					
positive . .	21	7	18	4	4
negative . .	0	0	1	4	1
Numbers of effects of phosphorus					
positive . .	31	20	31	20	19
negative . .	19	14	18	18	8
Significant effects:					
positive . .	7	0	7	4	1
negative . .	0	0	0	1	2
Numbers of effects of potassium					
positive . .	32	16	33	22	14
negative . .	18	18	17	16	12
Significant effects:					
positive . .	6	6	5	5	2
negative . .	2	3	3	1	1

one-fifth of all the experiments. Phosphorus had no significant effects on seed yields at individual centres and practically no effect on average of all the experiments. Yields increased by 2 per cent. on average with potassium; at six centres the increases were significant and at three other centres there were significant decreases in yield due to potassium.

Green-scutched Flax

Yields of green-scutched flax were measured in all except two of the 1940–4 experiments. The average increases obtained with nitrogen and with phosphorus were less than 2 per cent. of the mean yield; with potassium the mean yield increased by about 4 per cent. Increased yields with nitrogen were obtained at about three-fifths of all the individual centres; at four centres the increases were significant and at four other centres there were significant decreases in yields. Phosphorus increased yields significantly at four centres and potassium at five centres; each nutrient caused a significant decrease in yield in one experiment. On average, with nitrogen a slightly decreased percentage of scutched

flax was recovered from the deseeded straw; with potassium there was a small increase in the percentage recovery, while with phosphorus there was little average effect. With nitrogen a lower percentage of scutched flax was recovered in three-fifths of the experiments (there were seven significant negative effects and three significant positive effects). Negative and positive effects of phosphorus and potassium on percentage of flax recovered from straw were approximately equally numerous, and few of the increases were significant.

Retted-scutched Flax

Yields of scutched flax following retting were measured in nearly all of the experiments carried out between 1943 and 1945. On average of twenty-seven experiments yield increases of over 6 per cent. were obtained with nitrogen; positive effects were measured at more than

TABLE 4. *Summary of the Main Effects of Fertilizers, and Interactions, on Yields of Flax in Experiments carried out from 1941 to 1945.*

	Total crop	*Green-scutched flax*	*Retted-scutched flax*
Numbers of experiments	47	35	27
Mean yield (cwt./acre)	47·0	5·42	4·37
	Average effects of fertilizers on yields		
Main effects (in cwt./acre) *with*			
N	2·5	0·13	0·29
P	0·9	0·13	0·05
K	0·7	0·17	0·08
Interaction (in cwt./acre)			
NP	0·4	0·00	0·09
NK	0·3	−0·08	0·03
PK	−0·4	−0·02	−0·04
	Numbers of significant effects (P = 0·05 or less)		
	pos. *neg.*	*pos.* *neg.*	*pos.* *neg.*
Main effects			
N	19 0	4 4	4 1
P	7 0	4 1	1 2
K	6 2	5 1	2 1
Interaction effects			
NP	3 0	3 2	0 0
NK	1 2	0 0	0 0
PK	0 1	0 1	0 2

three-quarters of the centres and at four of these the increases were significant. Increased average yield of retted flax by about 1 per cent. was obtained with phosphorus and by nearly 2 per cent. with potassium; each nutrient gave very few significant effects. The average effect of fertilizers, on the percentages of scutched flax recovered after retting the straw, were smaller than those obtained for the recovery of flax following green scutching. With nitrogen a lower percentage of

retted-scutched flax was recovered in rather less than half of the experiments (one significant effect). With phosphorus there was a small average loss in recovery of retted flax, and there were three significant decreases at individual centres. Potassium significantly increased the percentage of retted flax recovered in two experiments; it caused a significant decrease in one other experiment.

Fertilizer Balance

The overall effects of individual fertilizers on flax yields were very small and there is little reason to expect appreciable and consistent effects from the action of one fertilizer on the response to another. This

TABLE 5. *Mean Effects of Fertilizers and their Interactions in Experiments on Flax which tested Agricultural Salt*

(*Twenty-eight experiments carried out in 1941–3 are averaged*)

	Total crop cwt./acre	*Deseeded straw cwt./acre*	*Green-scutched flax cwt./acre*	*Scutched flax as % of deseeded straw*
Mean yield . . .	46·4	31·8	5·56	17·7
Main effect of:				
N . . .	2·2	1·5	0·05	−0·5
P	0·7	0·6	0·12	0·2
K	0·3	0·2	0·11	0·2
S (Salt) . . .	−1·0	−0·8	−0·28	−0·4
Interactions				
NP . . .	−0·1	−0·1	−0·03	0·1
NK . . .	0·2	−0·2	−0·06	0·0
NS . . .	−0·2	−0·2	0·08	0·3
PK . . .	−0·1	−0·1	−0·04	0·0
PS . . .	0·2	0·2	0·02	0·0
KS . . .	−0·2	−0·1	−0·08	−0·2
NPK . . .	0·2	0·2	0·03	−0·1
NPS . . .	−0·5	−0·2	−0·08	−0·2
NKS . . .	−0·3	−0·2	−0·07	0·0
PKS . . .	0·0	0·2	0·03	−0·1

point is examined in Table 4 by stating for the 1941–5 experiments the average main effects of N, P, and K which have already been discussed, and their interactions. (The interactions are expressed as NP, NK, and PK; they are defined in the usual way so that the estimated effect of any fertilizer in the presence or absence of the other is obtained by adding or subtracting the appropriate interaction to or from the main effect.) The three experiments carried out in 1940 have been excluded as they were of different design. The average interactions of two nutrients were nearly all much smaller than the main effects of single nutrients. At individual centres the interactions were generally small. Significant interactions were much fewer than significant main effects and their numbers were not greater than the numbers which might be expected

to arise entirely by chance at the 0·05 level of probability. There is no case for recommending the singling out of any particular combination of fertilizers for flax.

Effects of Salt

Twenty-eight experiments of a standard pattern carried out between 1941 and 1943 tested 3 cwt. of agricultural salt per acre. The main estimated effects on yield, and interactions, in this series are summarized in Table 5. With salt the average yields of total crop, deseeded straw, and green-scutched flax were lower; the average percentage of scutched flax

TABLE 6. *Numbers of Positive and Negative Effects of Agricultural Salt on yields of Flax in twenty-eight Experiments carried out in 1941 to 1943*

	Numbers of effects of salt			
			Significantly	
	positive	*negative*	*positive*	*negative*
Yield of:				
Total crop	12	16	0	7
Deseeded straw	9	19	0	5
Green-scutched flax . . .	9	19	1	8
Scutched flax as per cent. of straw .	9	19	0	4

recovered from the straw was also less. The average decreases in yield in presence of salt were of greater magnitude than the corresponding increases in presence of phosphorus and potassium fertilizers. The effects of salt were examined in more detail by listing the numbers of positive and negative effects and the numbers of these which were significant; the data are summarized in Table 6. Decreased yields of total crop, deseeded straw, and green-scutched flax were obtained in presence of salt in more than half of the experiments; in a considerable number of experiments there was a significantly depressing effect of salt and there was only one instance of a significant benefit (on the yield of scutched flax at one centre in 1942). The percentage of scutched flax recovered from the straw was lower in the presence of salt at two-thirds of the centres and in four experiments this effect was significant. From the results of the three years' work it is clear that salt should not be used for flax.

Comparisons of Methods of Processing on the Effects of Fertilizers on Flax Yields

In nine experiments in 1943 and seven experiments in 1944 the straw was processed both by green-scutching and by retting followed by scutching. Mean yields and percentage recoveries of flax from straw are stated in Table 7, as averages for the comparable experiments. (Salt was included in the 1943 experiments and therefore the comparisons given in Table 7 are based on plots without salt so as to provide strictly

comparable data; some precision is lost by using only half of the plots of each of the 1943 experiments.) Lower average yields of flax were obtained with retting than with green-scutching in 1943; the two processes gave almost identical yields in 1944. In 1943 crops processed by retting showed an average benefit from nitrogen but yields of green-scutched flax showed no return with nitrogen manuring; in 1944 with nitrogen the average yields of flax produced by the two processes were

TABLE 7. *The Effects of Methods of Processing Flax on the Responses to Fertilizers in nine experiments in 1943 and seven experiments in 1944*

(Comparisons are made for 1943 on plots which were not treated with salt)

	1943		1944	
	Green scutching	*Retting and scutching*	*Green scutching*	*Retting and scutching*
Yield of scutched flax (cwt./acre)				
Mean yield	5·72	4·36	4·87	4·79
Effect of:				
N	−0·03	0·35	0·42	0·33
P	0·09	0·04	0·17	0·14
K	0·15	0·00	0·41	0·21
Scutched flax as per cent. of deseeded straw				
Mean value	16·6	12·7	14·4	13·8
Effect of:				
N	−0·9	0·4	0·2	−0·2
P	0·0	−0·1	0·5	0·2
K	0·7	0·3	0·5	0·2

similar. In both years the effects on yield with potassium were smaller when measured on retted flax than when the green-scutching process was used. Phosphorus had only small effects on yields of flax obtained with either process. At individual centres the estimated effects of fertilizers on yields of green-scutched flax and of retted flax were conflicting; the most extreme illustration of this was obtained in two of the 1943 centres where salt significantly reduced flax percentage for the green-scutching process and significantly increased it for the retting process. Yield data obtained by the green-scutching and by the retting processes had similar precision in 1943 but in 1944 yields of flax obtained by green-scutching were much less precise than those obtained by retting; the average standard errors per plot expressed as percentages of the general mean yield of flax were:

	1943	*1944*
Green-scutching	16·4	25·4
Retting and scutching	15·3	17·6

Comparisons of fertilizer effects on flax processed by the two methods make it more difficult to derive a recommendation for manuring the crop. Based on average yields of *all* experiments which were green-scutched the extra yields of scutched flax obtained with ammonium

sulphate barely paid for the dressing, but on the basis of those where the crop was retted a small but profitable return was obtained with nitrogen. The average return with phosphorus was not profitable whichever process was used. With potassium a profitable return was obtained on average of crops which were green-scutched but the return appeared unprofitable on average of all experiments which were retted (Table 2).[1]

TABLE 8. *Responses to Ammonium Sulphate obtained in Flax Experiments Grouped according to the Amounts of Nitrogen present in the Soils used and to the History of the Land*

	Number of experiments	Mean response cwt./acre	Numbers of significant effects: positive	Numbers of significant effects: negative
Centres grouped by soil analysis (1940–5 experiments)				
Nitrogen in soil (per cent.)		*Total crop*		
'low' (to 0·20)	19	2·8	7	0
'medium' (0·21–0·30)	20	3·0	10	0
'high' (over 0·30)	10	1·0	2	0
		Green-scutched flax		
'low'	17	0·14	3	2
'medium'	15	0·00	0	2
'high'	5	−0·07	0	0
		Retted-scutched flax		
'low'	8	0·38	3	0
'medium'	12	0·21	1	1
'high'	7	0·11	0	0
Centres grouped by history of the land (1940–4 experiments)				
		Total crop		
History:				
Arable	19	3·3	10	0
Ploughed-out	17	1·5	5	0
		Green-scutched flax		
Arable	18	0·18	2	0
Ploughed-out	16	−0·02	1	2

The Use of Soil Analysis to Improve Advice on Manuring of Flax

With crops which give small average returns from the use of fertilizers, and where effects vary from centre to centre, any method of identifying fields where profitable responses are likely to be obtained is valuable since manuring may then be concentrated on reponsive soils, the crops grown on other land being unmanured. Soil samples which were taken from practically all of the experimental sites were analysed. Total nitrogen was determined by the Kjeldahl method. Acid-soluble phosphorus and potassium were determined by two methods: the acetic acid method in which the soil was leached with 40 times its weight of 0·5N

[1] Statements of profitability made here imply simply that the extra crop obtained paid for the fertilizer dressing used; scutched flax has been assumed to be worth £12 per cwt.; 1958 subsidized fertilizer prices have also been assumed.

acetic acid; and the citric acid method in which the soil was shaken with 10 times its weight of 1 per cent. citric acid solution, extra citric acid being added equivalent to the calcium carbonate present when calcareous soils were analysed.

Responses to Nitrogen

The centres were divided into three groups according to the amounts of total nitrogen which the soils contained. The mean responses to ammonium sulphate, and the numbers of significant positive and negative effects, are stated in Table 8.

Nitrogen increased the yields of total crop significantly at nineteen centres and the soils at seventeen of these centres contained 0·3 per cent. of total nitrogen or less. One-fifth of all the soils contained more than 0·3 per cent. N and the average response in total crop with ammonium sulphate was only about one-third of the average response on the soils with lower nitrogen contents. Dividing the soils with 0·3 per cent. N or less into two groups ('low': to 0·20 per cent.; and 'medium': 0·21–0·30 per cent. N) did not assist in identifying the more responsive sites, as the average responses in total crop were almost identical for the 'low' and 'medium' groups. However, for green-scutched and retted-scutched flax the group of soils containing 0·2 per cent. N or less gave the largest average increase in yield; the groups of soils with 'medium' and 'high' soil nitrogen gave smaller responses in terms of retted-scutched flax and none in terms of green-scutched flax (the two series of experiments providing yields by the two methods of processing are not strictly comparable).

Many of the experiments were carried out on land ploughed from permanent grassland or from long leys, as part of the war-time programme for increasing the arable acreage. Flax was often grown on such land, as it was less subject than most other arable crops to attack by wireworms. Records of previous cropping over the three years before the experiments were laid down are available for practically all of the 1941–4 sites. The centres have been grouped in Table 8 according to their history; fields ploughed from grass within the previous three years are grouped together as 'ploughed-out', all other fields are classed as 'arable'. The 'arable' soils contained 0·19 per cent. total N on average; the mean value for the 'ploughed-out' soils was 0·28 per cent. N. The average increase in total crop yields given with nitrogen manuring on fields ploughed from grass was only half as great as the average response on 'arable' fields. With ammonium sulphate a small increase in yield of green-scutched flax was obtained on average of experiments on 'arable' fields but none on average of all the fields ploughed from grass. Consideration of the previous history of land can thus be used as an alternative method of selecting soils for nitrogen manuring. On the basis of yields of green-scutched flax, manuring would have been profitable on average of the group of soils on old arable land and also on average of all those soils containing less than 0·2 per cent. N. Either method of choosing fields for nitrogen manuring may fail to select a proportion of the land which should receive dressings.

Responses to Phosphorus

The experiments are grouped in Table 9 according to the amounts of citric acid-soluble and acetic acid-soluble phosphate which the soils contained, average responses by the crops to superphosphate are stated for each group. For the citric acid method it was possible to divide the soils into three groups, 'low', 'medium', and 'high' in soluble phosphate, so as to give a satisfactory distribution between the three

TABLE 9. *Responses of Flax to Superphosphate and the Numbers of Positive and Negative Effects in Experiments Grouped according to Soil Analyses*

Soluble P_2O_5 *(mg./100 g. of soil)*	*Number of experiments*	*Mean response cwt./acre*	*Numbers of significant effects*	
			positive	*negative*
Citric acid method				
		Total crop		
'low' (to 8)	12	3·0	5	0
'medium' (9–16)	14	0·4	2	0
'high' (over 16)	23	−0·1	0	0
		Green-scutched flax		
'low'	8	0·49	4	0
'medium'	10	−0·03	0	0
'high'	19	−0·04	0	1
		Retted-scutched flax		
'low'	8	0·24	1	0
'medium'	11	−0·15	0	3
'high'	8	0·14	0	0
Acetic acid method				
		Total crop		
'low' (to 5)	29	1·5	7	0
'medium' (6–15)	12	0·2	0	0
'high' (over 15)	8	−0·5	0	0
		Green-scutched flax		
'low'	20	0·20	4	0
'medium'	9	0·02	0	0
'high'	8	−0·16	0	1
		Retted-scutched flax		
'low'	20	0·01	1	2
'medium'	6	0·15	0	1
'high'	1	0·28	0	0

groups. These groupings distinguished between responsive and unresponsive sets of experiments. Where the content of citric-soluble soil phosphorus was classed as 'low', profitable average responses to superphosphate were obtained, both in terms of total crop yield and of yield of green-scutched flax. In the groups of soils having 'medium' and 'high' values for citric-soluble phosphorus, which together comprised more than three-quarters of all the centres, the average effects of super-

phosphate were small. Nearly all of the soils where significant increases in yields of total crop, or green-scutched flax were obtained contained 'low' amounts of citric-soluble phosphorus. Citric-acid soluble soil phosphate data were of little value in forecasting increases in yields of retted-scutched flax; on average of the groups of soils having 'low' and 'high' phosphorus values increased yields were obtained with superphosphate, but yield was lower on average of the group of soils having 'medium' values for citric-soluble phosphorus.

The acetic acid method was less useful than the citric acid method in picking out a small number of experiments where the average response to superphosphate was high, since twenty-four of the soils contained, per 100 g., 2 mg. or less of P_2O_5 soluble in this reagent. On average of the group of soils having 'low' acetic-soluble phosphate values, a profitable increase was obtained with superphosphate, but an increase in average yields was not obtained with this fertilizer in groups of experiments on soils having 'medium' and 'high' values for acetic-soluble soil phosphate. The acetic acid method did not distinguish those centres where superphosphate increased yields of retted-scutched flax. Of the two methods of soil analysis citric acid was much more useful than acetic acid. With either method farmers would be advised to apply superphosphate only to those fields with 'low' values for acid-soluble phosphate. Using the citric acid method 12 of the 49 fields would have received dressings of superphosphate which would have increased average yields on the 12 fields by 3 cwt. of total crop per acre. In contrast, use of the acetic acid method would have indicated that superphosphate should be applied to 29 fields. As the average response on those fields was only 1·5 cwt. of total crop per acre, the acetic acid method included in the 'low' group more of the less responsive or even unresponsive soils than did the citric acid method. Even by adjusting the limits of the 'low' group in the acetic acid method to 2 mg. P_2O_5 per 100 g. soil there were still 24 soils in the group.

Responses to Potassium

Average responses to dressings of muriate of potash, together with the numbers of significant positive and negative effects, are given in Table 10 after grouping the experiments by values for acid-soluble potassium in the soils used.

By using the limits indicated, the acetic acid method separated the centres into three groups containing roughly equal numbers of experiments. Yield increases with potassium fertilizer in terms of total crop, green-scutched flax, and retted-scutched flax decreased regularly with increasing values for acetic acid-soluble soil potassium; in addition the 'low' and 'medium' groupings picked out practically all centres where there were significant responses to potassium fertilizer. Values for citric acid-soluble soil potassium were much less successful in grouping the experiments. In both the groups of experiments having 'low' and 'medium' values for citric-soluble potassium increased yields of total crop and of green-scutched flax were obtained with muriate of potash dressings, and the average increases in the two groups were not markedly different.

In addition, half of the soils contained, per 100 g. of soil, between 7 and 10 mg. K_2O soluble in this reagent and only three soils had values of over 16 mg. K_2O per 100 g. The comparison of the three groups 'low', 'medium', and 'high' was therefore less satisfactory than for the acetic acid method. Both the acetic acid and the citric acid method were successful in distinguishing a group of centres having 'low' values for

TABLE 10. *Responses of Flax to Muriate of Potash and the Numbers of Significant Positive and Negative Effects in Groups of Experiments arranged according to Values for Soluble Soil Potassium*

Acid-soluble K_2O *(mg./100 g. of soil)*	*Number of experiments*	*Mean response cwt./acre*	*Numbers of significant effects*	
			positive	*negative*
Acetic acid method				
		Total crop		
'low' (to 10)	18	1·5	3	0
'medium' (11–16)	17	0·6	2	0
'high' (over 16)	14	−0·1	1	2
		Green-scutched flax		
'low'	14	0·48	2	0
'medium'	13	0·21	3	0
'high'	10	−0·10	0	1
		Retted-scutched flax		
'low'	8	0·35	1	0
'medium'	9	0·07	1	0
'high'	9	−0·15	0	1
Citric acid method				
		Total crop		
'low' (to 8)	19	0·9	2	0
'medium' (9–16)	27	0·7	3	2
'high' (over 16)	3	−0·1	1	0
		Green-scutched flax		
'low'	14	0·16	1	0
'medium'	21	0·29	4	1
'high'	2	−0·01	0	0
		Retted-scutched flax		
'low'	8	0·28	1	0
'medium'	16	0·02	1	0
'high'	3	−0·19	0	1

soluble soil potash where increased average yields of retted-scutched flax were obtained with muriate of potash.

There is a strong case for using measurements of citric acid-soluble soil phosphorus and acetic acid-soluble soil potassium in advising on phosphorus and potassium manuring of flax. By restricting manuring to the soils used in this investigation for which values were reported as 'low' in citric acid-soluble phosphorus, and as 'low' or 'medium' in acetic acid-soluble potassium, the methods would have picked out most of the fields which gave significant responses to superphosphate and to

muriate of potash respectively; the average extra yields of both total crop and of green-scutched flax would have given profits on the costs of the fertilizers used.

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PROBLEMS IN ADAPTING *LEUCAENA GLAUCA* AS A FORAGE FOR THE AUSTRALIAN TROPICS

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Summary

It is considered that *Leucaena glauca* could make a substantial contribution to the protein requirements of cattle over 96 million acres of tropical Australia. A high proportion of the strains examined can be classified under the lower-yielding Hawaii type. The vigorous and higher-yielding strains Peru, El Salvador, and Guatemala will be valuable in the breeding of improved types.

Flowering in this species commences at midnight and anthesis is restricted to about an hour from 7 a.m. to 8 a.m. *L. glauca* is self-compatible and mainly self-pollinated so that intra-strain variation is at a minimum. Significant inter-strain variation occurred in characters such as size of leaf and flower head and seed size and yield. Reproductive efficiency is low, the percentages of ovules producing seed being 0·8 and 0·04 in Hawaii and Peru respectively.

Efficient emasculation resulted when flower heads were shaken soon after anthesis in a solution of a non-toxic spreading agent. A number of successful crosses have been made and hybrid populations with sufficient variability for the selection of superior recombinants developed. Breeding for very low mimosine content is a major objective, and to achieve this it appears necessary to select first parental types with this character from within strains such as El Salvador.

Leucaena glauca Benth. is a species of tree native to Mexico and belongs to the family Mimosaceae of the Leguminosae. Dijkman [1] has summarized available information on its origin and characteristics, and Whyte, Nilsson-Leissner, and Trumble [2] have described its use as a forage. Cattle browse *L. glauca* readily and in Hawaii, Takahashi and Ripperton [3] found that it produced over a ton of protein per acre in a year. Anslow [4] in Mauritius obtained a yield of 2·8 tons of dry matter per acre containing 1,696 lb. of protein in an annual rainfall of 61·5 inches.

Where *L. glauca* comprises a high proportion of the diet of non-ruminants it can cause depilation, growth reduction, and general ill health [5]. Molina [6] found that the addition of 5 to 10 per cent. of *L. glauca* leaf meal to a standard chick ration increased its growth-promoting qualities. Ruminants are supposed not to suffer ill effects from grazing *L. glauca*. Damseaux [7], however, obtained symptoms of depilation, cessation of growth, and inflammation of the bladder in Suffolk sheep fed on this plant. Whyte, Nilsson-Leissner, and Trumble [2] state that *L. glauca* is suspected of causing sterility in cows although at the University Agricultural Experiment Station in Hawaii [8] the reproductive efficiency of cows fed *L. glauca* averaged 91·6 per cent. and was little different from those fed a diet free from this legume.

Yoshida [9] using rats proved that the loss of hair and other symptoms caused by diets containing seed or leaf of *L. glauca* was not due to selenium but to mimosine which she isolated from seed and fed in rations to her test animals. In Batavia, Kostermans [10] also extracted mimosine

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from *L. glauca* seed and found that it had no effect on monkeys, guinea-pigs, or rabbits, but caused depilation in pigs and horses. In horses it caused bare spots in the hair coat and loss of tail hairs and manes. He obtained similar results by feeding seed and leaves and found that regeneration of hair occurred. The chemistry and isolation of mimosine was studied by Bickel and Wibaut [11] who fed it in rations to mice and rats, the most definite symptoms occurring in the latter. Matsumoto and Sherman [5] have summarized data concerning the nature and structure of mimosine and developed a rapid colorimetric method for its estimation. Matsumoto, Smith, and Sherman [12] found that treatment of the leaf with moist heat above 70° C., or the addition of 3 per cent. ferrous sulphate to a ration containing leaf meal, reduced markedly the toxic effects of *L. glauca* to rats. Differences in mimosine content between strains of *L. glauca* have been noted by Matsumoto and Sherman [13] and Carangal and Catindig [14]. Arnold [15] and Gardner and Bennetts [16] state that toxicity of *L. glauca* is due to its ability to accumulate selenium from soils.

In view of the efficiency of *L. glauca* in producing protein the authors have examined all available strains of this species so as to define the problems involved in adapting it to the cattle country of tropical Australia. A study of the variation in the characters present within and between strains has been made. The breeding system has been observed and a new emasculation technique devised which has enabled the production of hybrid populations.

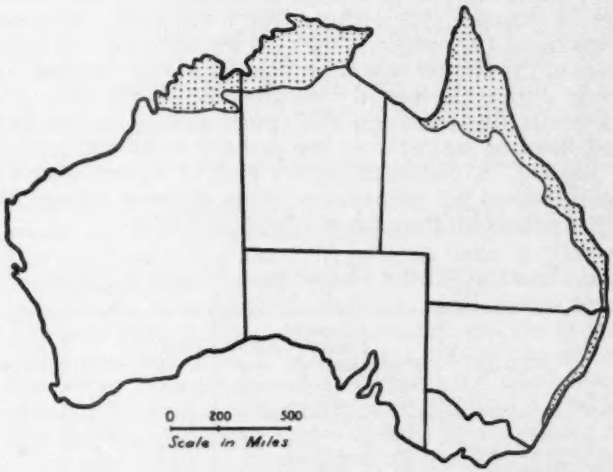
Potential in Australia

L. glauca is already naturalized in several areas of Northern Australia. Collections have been obtained in Queensland from Brisbane, Gympie, Gayndah, Rockhampton, Mackay, and Innisfail, and also from Darwin in the Northern Territory. All these collections are early, fine-leaved, and free-seeding in habit, and are similar in type to the strain introduced from Hawaii. It is possible that the Australian occurrences stem from seed brought from trees growing in New Guinea and Fiji.

From the results of field trials, and from its natural distribution, it appears that *L. glauca* could be grown successfully in Australia where the annual rainfall is 30 inches or more, with a summer incidence, and where the July mean minimum temperature does not fall below 50° F. This area, which includes part of tropical and sub-tropical Australia, is shown in the map and covers approximately 144,000 square miles in Queensland, 95,000 square miles in the Northern Territory, 50,000 square miles in Western Australia, and 13,000 square miles in New South Wales. If *L. glauca* could be grown on half this area it would mean a potential of some 96 million acres for this species.

At the C.S.I.R.O. Pasture Research Station, Samford, near Brisbane, a cutting trial was conducted in the 1955–6 summer season with three strains using samples of ten trees from a stand 2 years old. The trees were cut back 12 inches above ground-level, and two harvests of the subsequent regrowth over 10 weeks yielded 6·6 tons per acre of green herbage from Peru, 4·2 tons from El Salvador, and 2·9 tons from Hawaii.

Dry matter of old leaves contained a mean of 18·5 per cent. protein and that of young tip leaves a mean of 29·8 per cent. protein. At Rodd's Bay, Queensland, N. H. Shaw (personal communication) harvested from the Hawaii type 0·5 tons per acre of oven-dry leaf (excluding twigs) with a 25 per cent. protein content. This was obtained in spring after deferment of grazing from the end of summer. It is apparent that *L. glauca*, and particularly some strains, could make a substantial contribution to the protein requirements of cattle in Australian tropical regions.



Area where *L. glauca* could be grown in Australia.

An important characteristic of this species is its ability to hold leafage in a green state during winter and spring when pasture protein is at its lowest level. Thus *L. glauca* is capable of providing leafage when other summer legumes are dormant as well as growing vigorously during the summer season. *L. glauca* proved its drought resistance by growing actively at the C.S.I.R.O. Pasture Research Station, Samford, through the spring and early summer of 1957, when 53 per cent. of the mean rainfall of 9·8 inches for the period 1 September to 31 December was received.

Variation Within and Between Strains

Thirty-three accessions have been grown at the C.S.I.R.O. Pasture Research Station, Samford. These include strains from El Salvador, Guatemala, Peru, Hawaii, the Philippines, Rhodesia, New Guinea, Fiji, New Caledonia, and Queensland. These have been examined to determine the extent of inter- and intra-strain variation. During the 1955–6 season seven strains were selected for detailed examination and data were obtained from samples of ten plants of each from a stand 2 years old

There was a high degree of uniformity within strains in plant height, growth habit, time of flowering, leaf size, size and shape of pods, seed

yield, and seed size. Two plants of the El Salvador strain and one of the Peru differed in maturity from the rest of the sample, and in the former strain there was a marked plant to plant variation in the intensity of red pigmentation of the petioles.

Strains of *L. glauca* can be grouped into three types on the basis of maturity, vegetative vigour, and yield. The Hawaii, El Salvador, and Peru strains are representative of the three types. In this order they show increasing vigour and decreasing earliness of maturity. Thirty of the strains examined can be classed as belonging to the Hawaii type, while the El Salvador type includes one other strain, Guatemala, and the late-maturing Peru strain is the only representative of its type. An early strain of the Hawaii type from Bald Hills, near Brisbane, flowered consistently during the period December to March. Hawaii and the similar Darwin, Rhodesia, and Philippines strains were mid-season in habit and flowered mainly over the January to March period, with a peak in January. El Salvador, with a peak of flowering in February, could be classed as late mid-season. Peru flowered during the period February to May with the peak in March and April.

TABLE 1. *Strain Characters in* Leucaena glauca

Strain	*Maturity class*	*Plant height cm.*	*Primary mid-rib length of leaf mm.*	*Flower-head diameter mm.*	*Floret no. per head*	*Pod length mm.*	*Seed yield per plant g.*	*Seed size mg.*
Bald Hills	Early	121†	107†	24†	138†	138	131	33·0
Hawaii	Mid-season	180	130	26	179†	138	178	29·3
Philippines	Mid-season	182	130	26	161	147	252	35·3
Rhodesia	Mid-season	214	147	26	164	140	236	29·9
Darwin	Mid-season	226	151	27	160	136	225	33·8
El Salvador	Late-mid-season	228	171†	27	166	142	326†	37·6
Peru	Late	305†	145	29†	140†	165†	27†	45·8†

† These values are significantly different at the P = 0·01 level from the other values for the same character except that in floret number per head Bald Hills and Peru are not significantly different.

Significant inter-strain differences in plant height, size of leaf and flower head, floret number per head, pod length, and seed size and yield were found only between the three types of *L. glauca*. Strain variation within the types was usually not great enough to be significant, except in the case of the Bald Hills strain. The characteristics of seven representative strains are listed in Table 1.

Bald Hills had a significantly smaller plant height, primary mid-rib length of leaf, floret number per head, and seed yield than Hawaii, Darwin, Rhodesia, and Philippines between which there were no significant differences in these characters. Peru had a significantly greater plant height, flower-head diameter, pod length, and seed size than the other strains, but had the lowest seed yield per plant and shared with Bald Hills the lowest floret number per head. El Salvador had the greatest primary mid-rib length of leaf and the highest seed yield per plant, but was similar to the Hawaii type strains in other characters.

Seed Setting

Seed setting and some of the characters associated with it were investigated in four strains at the C.S.I.R.O. Pasture Research Station, Samford. Samples of ten trees of each strain were selected at random from a stand 2 years old. The results are summarized in Table 2.

TABLE 2. *Characters Associated with Seed-setting in* L. glauca

Strain	*No. of flower heads per plant*	*No. of pod clusters matured per plant*	*No. of pods matured per plant*	*No. of seeds per plant*	*Percentage of ovules producing seed*
Bald Hills .	166	70	277	3974	1·0
Hawaii . .	265	118	388	6058	0·8
El Salvador .	466	130	545	8666	0·7
Peru . .	666	20	45	585	0·04

The Bald Hills, Hawaii, and El Salvador strains produced more than sufficient seed for their propagation, but Peru, as shown previously, was deficient in this respect and would be more so under a grazing régime. In addition, the germinating capacity of Peru seeds was less than that of the other strains. Under field conditions regeneration by seedlings occurred in Bald Hills, El Salvador, and Hawaii, but not in Peru.

Reproductive efficiency of *L. glauca* as a species was low when the percentage of ovules producing seed is considered. Peru was particularly inefficient and this would restrict its immediate utilization in the field. This may be associated in part with its later maturity relative to the Samford environment, although trees of the Peru strain grown 320 miles north of Brisbane still set seed poorly compared with those of the El Salvador and Hawaii strains. Furthermore, seeds of Peru matured slowly and this may partly explain the high proportion of poorly developed seed. Pistil abnormalities may also have contributed to the poor seed-setting of Peru. Observations on five flowers of both Peru and Hawaii taken at random from different trees showed that 19 per cent. of the 710 pistils of Peru and 1 per cent. of the 902 pistils of Hawaii were abnormal. The commonest aberration was a 'kinked' style which could interfere with pollination and pollen-tube growth.

Selection for Low Mimosine Content

Published evidence is definite that mimosine, which is identical with leucanol or leucanine, is the toxic principle of *L. glauca*. In the authors' experiments with mice (unpublished data) feeding meal diets containing *L. glauca* seed or leaf gave similar toxic effects to one containing an equivalent quantity of pure mimosine. The authors have been unable to substantiate the statements of Arnold [15] and Gardner and Bennetts [16] that the toxicity of *L. glauca* is due to its selenium content, and they agree with Yoshida [9] that this element is not involved.

Mr. N. H. Shaw (personal communication) obtained loss of hair from the tails and rumps of cattle grazing plots of *L. glauca* at Rodd's Bay.

Seeds and dried-leaf samples of *L. glauca* from Rodd's Bay, from the C.S.I.R.O. Pasture Research Station, Samford, and from the Gatton Agricultural College, Lawes, were analysed for selenium by Mr. C. W. R. McCray of the Queensland Department of Agriculture and Stock using the method of Trelease and Beath [17]. No selenium could be detected in the samples but the dried leaves contained 3 to 4 per cent. mimosine. It appears that selection for low mimosine content would be advantageous in *L. glauca*.

During the 1955–6 season young tip leaves of twenty plants of each of six strains of *L. glauca* were analysed for mimosine content by the method of Matsumoto and Sherman [5]. The results are summarized in Table 3.

TABLE 3. *Mimosine Content of Six Strains of* L. glauca

Group	*Strain*	*Mean % mimosine on a dry basis*	*Range in individual plants*
1	Guatemala	1·63	0·95–3·12
1	Bald Hills	1·86	1·20–3·11
1	El Salvador	1·87	0·45–2·74
2	Gayndah	2·67	1·86–4·26
2	Peru	2·77	2·00–3·46
3	Hawaii	3·79	0·48–6·00

Guatemala, Bald Hills, and El Salvador constitute a group which has the lowest mimosine content. Hawaii has the highest mimosine content with Gayndah and Peru being intermediate in this respect. These inter-group differences are significant, and although the mimosine levels are lower than those reported by Matsumoto and Sherman [13] the authors' results are in agreement with theirs in showing that El Salvador has one of the lowest mimosine contents.

Most of the intra-strain variation obtained in this experiment is considered to be due to differences in maturity of the tip leaves rather than to genetic differences. Recent results with seedlings suggest that occasional plants within a strain such as El Salvador have a significantly lower or higher mimosine content than the mean for the strain. It is possible that plants with a very low inherent mimosine content could be selected from seedling progenies raised from the seed of strains or inter-strain crosses.

Breeding System and Mode of Flowering and Pollination

In a flower bud immediately prior to opening, the filaments and style are bent and rather closely packed inside the space enclosed by the valvate petals. The first stage of anthesis consists of the separation of the corolla segments and the straightening of the filaments and style. At the height of flowering in mid-summer, flower buds open soon after mid-night. At sunrise, about 5 a.m., the anthers have not dehisced and stand about 1 mm. above the level of the stigmas. Bees are active in fine weather on the newly opened flowers. Anther dehiscence takes place

about 7 a.m. to 8 a.m. and in any particular flower head is completed within half an hour. The clumped pollen falls directly on to the stigmas and pollen grains become lodged in the stigmatic cups, where they germinate. This ensures a high degree of self-pollination. By 10 a.m. the anthers have retracted so that the stigmas stand about 1 mm. above the anthers. Visits by bees are infrequent at this stage, which would be when cross-pollination could most easily take place. In addition, no pollen is being shed by any flowers at this stage and no further flowers open until next morning. By early afternoon the anthers have turned brown and are retracted further so that the stigmas stand out prominently.

Selfing flower heads with porous-type cellophane and white paper bags usually gave settings of pod clusters similar to those of unbagged controls, except in hot sunny weather when cellophane bags gave a reduced pod set. Under these conditions a temperature of about 39° C. was maintained inside the cellophane bags and this was 4 to 5° C. higher than in white paper bags and in the open air. It is apparent that *L. glauca* is self-compatible. First- and second-generation progenies resulting from natural pollination of any particular strain showed no more intra-strain variation in morphological characters than the original introduction. Although the possibility of some cross pollination cannot be ruled out, owing to the mode of flowering, it is evident that *L. glauca* is predominantly self-pollinated and self-fertilized.

Method of Emasculation and Hybridization Developed

The small size of the flowers, and the fact that some 140 to 180 florets are bunched together in a flower head, made it impracticable to emasculate by hand in the usual way. As flowering occurs only once a day and anther dehiscence is limited to about half an hour, it was possible to develop a satisfactory emasculation technique. This involves shaking the flower heads for 3 minutes in water containing a non-toxic spreading agent soon after dehiscence between 8 a.m. and 9 a.m. In this work a 0·1 per cent. solution of Gardinol K, a sulphonated lauryl alcohol, was used. This removes or renders inviable the pollen grains in the stigmatic cups. After the heads have dried in about an hour, pollen from the male parent is applied to the stigmas with the fingers. Microscopic examination of crossed flowers showed that small clumps of pollen became lodged in the stigmatic cups. Crosses were made successfully both in the field and with potted plants in a glass-house.

Pollen for use in crossing was collected in porous type cellophane bags placed over the flower heads of the male parent the day before flowering. Flower heads at the right stage are usually deep yellow in colour. The pollen grains which were shed cohered into large aggregations which were difficult to handle with a brush. The cohesive tendency of the pollen was not reduced by drying in air-tight jars containing silica gel.

Two separate experiments were done to test the efficiency of the emasculation technique developed. In one, different pairs of flower heads of the Hawaii strain in full flower were treated with a 0·1 per cent. solution of Gardinol K for 3 minutes and 6 minutes respectively at each

of four different times during the day of opening, untreated controls being labelled each time. At the end of the day all the treated heads and controls were removed and placed in ethanol-acetic fixative. Subsequently the stigmatic cups were stained with basic fuchsin in lactophenol and the number of pollen grains remaining in them counted. The results are given in Table 4.

TABLE 4. *Effect of Shaking Flowers of the Hawaii Strain in 0·1 per cent. Gardinol K Solution at Different Times of the Day*

Time of treatment	*Mean no. of pollen grains per stigmatic cup*		
	Untreated	*Washing 3 mins.*	*Washing 6 mins.*
8.30–9.00 a.m.	14·9	0·5	0·9
9.30–10.00 a.m.	11·1	6·0	6·0
10·30–11.00 a.m.	13·0	7·6	8·8
1.30–2.00 p.m.	10·1	13·4	11·0

This experiment shows that efficient emasculation was obtained only when the flowers were treated soon after anthesis. No advantage was gained by increasing time of shaking from 3 to 6 minutes.

The objective of the second experiment was to measure the effect of Gardinol K treatment of newly opened flowers on subsequent seed-set. At each of five different times during the day of opening seven flower heads of the Gympie strain, an Hawaii type, were shaken for 3 minutes in 0·1 per cent. Gardinol K solution and then bagged. The results are summarized in Table 5.

TABLE 5. *Effect on Pod Set of a 3-minute Shaking of Flowers of the Gympie Strain in 0·1 per cent. Gardinol K Solution at Different Times of the Day*

Treatment time . .	nil	8.30–8.45 a.m.	8.45–9.45 a.m.
Mean no. pods/head .	7·9	0·0	1·7
Treatment time . .	9.45–10.45 a.m.	10.45 a.m.–12 noon	1.30–3.45 p.m.
Mean no. pods/head .	2·3	6·9	8·0

As in the previous experiment efficient emasculation was obtained only when the flowers were treated with Gardinol K within about an hour after anthesis. It is apparent that this treatment will reduce seed-set markedly up to about 3 hours after anthesis.

A further experiment was done in which emasculation by the Gardinol K treatment within an hour after anthesis was followed with cross-pollination by hand. Details of this are given in Table 6. Four strains were involved: Bald Hills, Hawaii, El Salvador, and Guatemala.

Although the untreated controls set more pods and seed than the cross-pollinated flowers, sufficient seed of each cross was obtained to raise an F_1 population. That natural cross-pollination was not usual after the emasculation treatment was shown in another experiment in

which twenty flower heads were emasculated soon after anthesis and were left unbagged. All of these abscissed without forming pods.

A high proportion of the F_1 crosses, notably Peru × El Salvador, Hawaii × El Salvador, and Bald Hills × Guatemala, have exhibited hybrid vigour. In addition the red petiole colour of Peru has been dominant in all crosses where this strain was used as the male parent.

TABLE 6. *Pod- and Seed-set in* L. glauca *following Emasculation and Cross-Pollination*

Treatment	*No. of flower heads*	*% of heads setting pods*	*Mean no. pods/head*	*Mean no seeds/pod*
Shaken in Gardinol K and bagged .	7	0·0	0·0	0·0
Shaken in Gardinol K, cross-pollinated, and bagged	43	44·2	1·9	12·3
Untreated controls bagged . . .	22	63·6	4·2	15·1

Adaptation to the Australian Environment

There are distinct possibilities that *L. glauca* could provide substantial quantities of protein for cattle in extensive areas of Australian tropical coastal and sub-coastal country. The fact that it is already naturalized in different areas of this zone indicates that it could be adapted successfully to the environment. The naturalized strains are similar to the lower-yielding Hawaii, in fact 90 per cent. of the authors' accessions can be classified as the Hawaii type. This means that the Hawaii type occurs over a wide area which includes Australia, New Guinea, Fiji, New Caledonia, Hawaii, and the Philippines.

For *L. glauca* to be really successful in Australia it will be necessary to develop strains which are quicker growing and higher yielding than Hawaii. The strains from El Salvador, Guatemala, and Peru possess these characteristics but are not low enough in mimosine content. In addition, the most vigorous strain, Peru, set seed poorly under our conditions. The 'gene pool' available in this species makes it possible to breed for Australian conditions a vigorous high-yielding strain with good seed-setting ability and with a very low mimosine content.

Mimosine is the toxic constituent of *L. glauca* and there is no evidence to suggest that selenium is involved. Although ruminants are considered to be unaffected by the mimosine of *L. glauca*, N. H. Shaw's results with cattle at Rodd's Bay and the experiments of Damseaux [7] with Suffolk sheep in the Belgian Congo show that selection for very low mimosine content should be an essential part of any breeding programme with this species.

The mode of flowering and pollination in *L. glauca* reduces the amount of variability available for selection within strains. However, a small degree of cross-pollination is probably taking place as evidenced by a limited amount of variation in certain characters within strains. It appears that most of the morphological characters which the authors have examined have a multigenic basis so that any intra-strain variations

in them would not be detected easily by the system of measurement used. Intra-strain variations in mimosine content, however, can be detected because of the sensitivity of the chemical test. This is important for the selection of parental types to be used in the breeding of strains very low in mimosine content. For the selection of new strains possessing all the desired characters a wide range of variability can now be produced in populations by intercrossing strains using the techniques described in this paper.

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SOIL FERTILITY STUDIES IN THREE AREAS OF TANGANYIKA

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Summary

The results of over 200 field experiments on soil fertility problems in the Southern, Central, and Western Provinces of Tanganyika are summarized. In most of the experiments the crop was groundnuts or maize but a few experiments with sunflower, sorghum, soya, safflower, castor, and tobacco are also included.

In the Central Province inadequate or poorly distributed rainfall severely restricted yields.

All soils in the Southern Province and the upland soils in the Central Province tend to phosphorus deficiency. In the south, valuable first-year residual effects of fertilizer phosphorus were found. In the Western Province analysis suggests that the soils have a higher phosphorus status; responses to phosphatic fertilizers were variable and not clearly related to soil type. A fair relationship was obtained between response to phosphorus by groundnuts and soil phosphorus extracted with dilute hydrochloric acid, for the soils of the Southern Province and the red soils of the Western Province; in the Southern Province the greatest response was achieved with only 10 lb. P per acre and other evidence is presented which suggests that groundnuts can use only very limited amounts of phosphorus. With maize the responses increased with the successive additions up to 30 lb. P per acre. Single and 'triple' superphosphate were the most satisfactory phosphatic fertilizers but calcium metaphosphate and dicalcium phosphate gave good results.

In the Southern and Western Provinces ammonium sulphate produced large responses in non-leguminous crops and for these the NP interaction was important. In none of the areas did groundnuts respond to ammonium sulphate, indicating the effectiveness of their nodules. This lack of response, and other evidence, shows the soils of all areas to be adequately supplied with sulphur.

The soils of all areas have adequate potassium for the majority of crops and only with tobacco were responses obtained. Tobacco, however, has a high potassium requirement and potassium fertilizer was essential for this crop in the Western Province.

Only on the acid Mtanana soils of the Central Province were there responses to limestone.

The only trace-element deficiency observed was that of iron on low-lying alkaline soils in the Central Province.

General Description of the Areas and Scope of the Investigations

THE work reported in this paper was carried out in 1947–52 as an activity of the Scientific Department of the East African Groundnut scheme. Its aim was to obtain, over a period of years, knowledge which would guide policy on soil fertility for the large-scale mechanical agricultural development envisaged in the Southern, Central, and Western Provinces of Tanganyika at Nachingwea, Kongwa, and Urambo respectively [1]. The investigations comprised a wide range of field experiments, supported by chemical analysis of soil samples, in which the soils of agricultural importance were studied. In addition to groundnuts, all other

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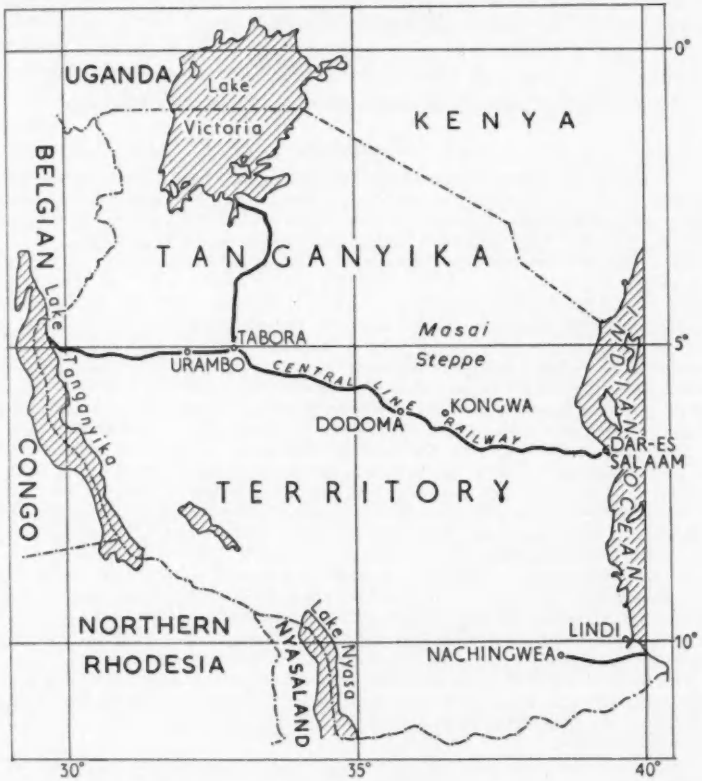
crops likely to be grown in the areas to be farmed by the Overseas Food Corporation were included in the experimental programme.



In all areas the land was under indigenous forest or bush until 1947 and the experimental work followed immediately after the land clearing. Good experimental sites were often scarce so that many repetitions of each type of experiment were necessary. Some 280 experiments were laid down, of which about one-quarter were either not completed or regarded as unreliable for various reasons. Results from over 200 experiments are presented in this paper.

Experimental designs and methods

In 1947 very little information was available on the fertility of the soils in the three areas, so that the majority of the early experiments were exploratory. For this purpose 2^4 factorial designs were used to measure crop responses to added nitrogen, phosphorus, potassium, and calcium. At the start it was thought likely that phosphorus would prove to be deficient in most of the soils and so experiments were designed to test a

range of different phosphatic fertilizers and to determine the response curve for the standard material, superphosphate. In the high-rainfall areas of the Southern and Western Provinces experiments on the rate and time of application of nitrogenous fertilizer were carried out with non-leguminous crops.

For experiments which involved only one rate of application of a fertilizer, the standard rates adopted were:

Nitrogen:	11 lb. (0·1 cwt.) N per acre for legumes.
	45 lb. (0·4 cwt.) N „ „ non-legumes.
Phosphorus:	25 lb. P (0·5 cwt. P_2O_5) per acre for all crops.
Potassium:	56 lb. K (0·6 cwt. K_2O) per acre for all crops.
Calcium:	8 cwt. per acre ground limestone for all crops.

The standard materials used were ammonium sulphate, superphosphate, and muriate of potash.

In the first two seasons (1947–8 and 1948–9) the nitrogen, phosphorus, and potash fertilizers were mechanically placed, at the time of planting, about 1½ inches each side of the seed and approximately level with it. Experience showed that ammonium sulphate thus applied seriously depressed the germination of certain seeds, particularly sunflower, so that in 1949–50 and later all ammonium sulphate was applied as a top dressing about 6 weeks after planting. Other fertilizers continued to be placed as before. Limestone was broadcast and disked into the surface soil before planting.

In early experiments the crops were grown on flat land but in later years 'tied ridges' were adopted to avoid soil and water movement. The ridges were made mechanically after the limestone (if any) had been broadcast; the P and K fertilizers were placed, and the seed planted mechanically, on the preformed ridges. Finally, adjacent ridges were joined, or tied, at intervals of about 3 yards by a ridge of soil scraped from the furrow. Thus a series of basins was formed and movement of soil and water was prevented. Detailed accounts of tied-ridge cultivation have been given by Prentice [2] and Le Mare [3].

Description of the areas: climate, vegetation, and soils

The Southern Province area, which has Nachingwea (lat. 10° S., long. 39° E. approx.) as its centre, lies about 100 miles from the Tanganyika coast at 1,200 to 1,500 feet above sea-level. Although the mean annual rainfall is about 33 inches, falling during December to April, variation from year to year is considerable. Evans [4] has discussed crop production in the Southern Province in relation to rainfall reliability and gives data for Masasi, 23 miles south of Nachingwea. These data show that any total between about 20 and 45 inches may be expected to occur as often as any other. In none of the thirty-two years studied was the rainfall less than 20 inches. Crop failures due to drought, such as occur from time to time in other parts of Tanganyika, particularly the Central Province, are rare in the Southern Province, although poor distribution of rainfall within seasons may reduce yields.

The Western Province area lies around Urambo (lat. 5° S., long. 32° E.

approx.) at 3,500 to 4,000 feet above sea-level. The rains start towards the end of October or early November and continue until April or May. During the period 1948–54 the annual rainfall varied from 25 to 52 inches. In 1949, when 25 inches fell, the distribution during the season was unsatisfactory, only 5½ inches falling during February and March; although 8 inches fell in April crops did not recover from the check in growth already experienced and yields were not high.

The Central Province area lies at the southern end of the Masai steppe. The experimental work was carried out 10 miles north of Kongwa (lat. 6° S., long. 36° E. approx.), a small village at the foot of the Kiboriani range of mountains. The area as a whole is at 3,500 to 4,000 feet above sea-level but the mountains to the west and south rise to 6,000 feet. The climate is marginal and the incidence of drought years has led the Tanganyika Agricultural Corporation to replace arable agriculture by cattle ranching. The rainfall season is from December to April and during the years 1948–54 the seasonal total varied between 5 inches in 1953 and 27 inches in 1951; it was below 15 inches in three of the seven years. The distribution of the rainfall during the season, both in space and time, tends to be unfavourable even in years of greatest precipitation. The experimental work now reported was carried out during 1948 to 1952, a period which included only one year, 1949, when crop failures were general; hence the yields presented are probably an over-estimate of the agricultural potentialities of the area. The rainfall in the foothills of the mountains, where the greater part of the peasant cultivation is practised, may be slightly better than on the plain, but food shortages due to drought are not uncommon in the Central Province.

Vegetation and Soils

The vegetation and soils of the areas have been described in the Annual Reports of the Scientific Department of the Overseas Food Corporation [5]. The soils of the Southern and Central Provinces have been described by Muir, Anderson, and Stephen [6], and by Anderson [7]. Grantham and Pilson [8] have also discussed the soils of the Southern Province.

All areas show a mature topography, gently undulating with broad drainage lines which in the south and west are swampy but in the Central Province form grassy plains with scattered trees, especially towards the margins.

In the Southern Province area the natural vegetation is Miombo forest (Isoberlinia–Brachystegia open woodland association) but shifting peasant cultivation has modified the climax forms considerably and has led to great variety within the Miombo forest. The Southern Province soils, like those of the other areas, are underlain by rocks of the Lower Basement Complex. The soils form a catenary sequence, the agriculturally important members being the red or red-brown loams and sandy loams of the higher ground. In this paper no attempt is made to relate fertilizer responses to the classification of the soils of the Southern Province area since there was a high degree of consistency in the responses obtained over the area.

The vegetation of the Urambo area is also open Miombo woodland

in which various grasses form a light ground cover. The two soil types of agricultural importance are the red loams of the higher ground and the sands of the middle and lower slopes. The valley and drainage channel soils were not cultivated. The red loams are deep and well drained; the top soil of about 8 inches is underlain by 15 to 20 feet of orange subsoil in most places. The sands are grey in colour at the surface but change at 6 to 8 inches to a pale yellow subsoil. During the wet season the water-table in these soils may rise to within 2 feet of the surface. The effect of the high water-table and of impoverished subsoil on root development and crop growth at Urambo has been discussed by Hagenzieker [9] who has shown marked effects of subsoil placement of fertilizer. Analyses of surface samples of the red loams and sands at Urambo are given below:

		Exchangeable cations m.e. %			P *extracted by* 0·3 N HCl
	pH	K	Ca	Mg	*p.p.m.*
Red loams . . .	6·6–7·5	0·4	2·8	1·0	6
Sands . . .	6·1–8·0	0·3	2·7	0·8	11

The principal soils of the Kongwa, Central Province, area are the red loams and buff sandy clays of the higher ground, and the valley or 'mbuga' soils of the low-lying, grassy plains. The red soils, mostly belonging to the Chamaye series, are deep and well drained and show little profile differentiation; their pH is about 6·5. The buff-coloured soils, the Mtanana series, are very poor; they have pH of 4·0 to 5·0, are poorly drained and contain ironstone concretions or massive ironstone at 2 or more feet below the surface. They have been little used for agriculture. The experimental results for the upland soils presented in this paper are almost entirely from the red soils but on pp. 217–18 the results of some experiments on the amelioration of the more acid, poorly drained soils of the Mtanana series are given.

The valley soils at Kongwa are grey clays, neutral to alkaline, overlying the calcium carbonate which may be either concretionary or lacustrine depending upon position. Most of the experiments on valley soils were on soils of the Lubiri series but others on the Mankhunze and Lower Kibumbuni series are also included. Typical analyses obtained from a large number of samples of the surface soils of the Kongwa area are given below.

		Exchangeable cations m.e. %			P *extracted by* 0·3 N HCl
Series	*pH*	Ca	Mg	K	*p.p.m.*
Upland soils					
Chamaye . . .	5·1–7·5	4·9	2·0	1·0	3
Mtanana . . .	4·1–6·0	2·3	1·6	0·8	3
Valley soils					
Lubiri . . .	7·1–8·0	24·0	13·7	3·0	5
Mankhunze . .	7·1–7·5	12·0	4·2	2·0	2
Lower Kibumbuni .	8·1–9·0	30·2	6·0	1·5	29

Presentation of the data

In presenting the experimental results in this paper all yields and responses are given in pounds per acre of produce (groundnut kernels, sunflower 'seed', soya-bean seed, maize, and sorghum grain). In some instances the percentage response, i.e.

$$\frac{\text{response to treatment}}{\text{yield without treatment}} \times 100,$$

is also given in order to facilitate the comparison of the responses of a variety of crops to a particular treatment.

The full data from which this paper has been prepared are available for reference at the Commonwealth Bureau of Soils, Harpenden.

Nitrogen

Information on crop response to nitrogen is available from about 100 experiments, covering the three areas and a range of crops. In all these experiments a basal dressing of superphosphate was given; nitrogen was applied as ammonium sulphate. The possibility that sulphur contributed to the responses is shown to be unlikely by evidence presented later and the effects of ammonium sulphate are therefore considered to be due to nitrogen.

The responses of non-leguminous crops to 45 lb. N per acre are presented in Table 1. Maize responded to nitrogen in all areas. At Nachingwea, in eighteen experiments over four years, the mean increase in yield was 495 lb. or 40 per cent. of the yield without fertilizer. Responses at Urambo were 570 and 664 lb. grain per acre on the red loams and sands respectively. The red loams gave a rather higher yield than the sands in the absence of added nitrogen, and the percentage responses were 63 and 86 respectively. At Kongwa there were only two maize experiments, one on each soil type, both in years of good rainfall. On both soil types yield was increased by about 400 lb. grain per acre by the additional nitrogen.

Sunflower yields, which were not generally high, were also increased by additional nitrogen at both Nachingwea and Urambo. At Kongwa yield of sunflower and other non-leguminous crops (except maize), was not increased by fertilizer nitrogen.

The effect of ammonium sulphate on groundnuts is shown in Table 2. At the outset of the experimental work it was thought that on newly cleared land nitrogen fixation by the root-nodule bacteria might be inadequate and so the effect of ammonium sulphate was investigated. In none of the areas was the mean response large, although at Nachingwea there was a group of three experiments in 1950 in which the response averaged 260 lb. kernels per acre, but in only one case did it reach statistical significance. In two soya-bean experiments at Nachingwea there was no increase in yield from 11 lb. N per acre.

In two experiments at Nachingwea in 1951 rates of nitrogen up to 66 lb. N per acre were applied to groundnuts but no response was obtained. It seems, therefore, that in these areas nitrogen is generally supplied in adequate amounts by the activity of the root-nodule bacteria.

TABLE 1. *Effect of 45 lb. Nitrogen per acre as Ammonium Sulphate on Non-leguminous Crops (lb. produce per acre)*

	No. of years	*No. of experiments*	*Mean yield without* N	*Mean response to* N	*% response*
Nachingwea					
All soils:					
Maize	4	18	1,240	495	40
Sunflowers	1	4	606	125	21
Urambo					
Red loams:					
Maize	2	5	899	570	63
Sands:					
Maize	4	9	772	664	86
Sunflower	1	3	432	157	36
Kongwa					
Upland soils:					
Maize	1	1	1,622	374	23
Sorghum	1	2	888	59	7
Castor	1	1	652	−103	..
Sunflower	2	4	260	−20	..
Valley soils:					
Maize	1	1	2,390	432	18
Sunflower	2	6	600	12	2
Sorghum	1	1	810	44	5
Safflower	1	1	534	−29	..

TABLE 2. *Effect of 11 lb. Nitrogen per acre as Ammonium Sulphate on Groundnuts (lb. kernels per acre)*

	No. of years	*No. of experiments*	*Mean yield, without* N	*Mean response to* N	*% response*
Nachingwea					
All soils	3	17	1,084	68	6
Urambo					
Red loams	1	2	754	13	2
Sands	1	3	956	5	1
Kongwa					
Upland soils	4	12	698	7	1
Valley soils	3	6	512	59	12

Nitrogen-phosphorus interaction

The reported responses to nitrogen by non-leguminous crops were all obtained in the presence of added fertilizer phosphorus. Similarly, the responses to phosphorus, which are reported on pp. 207–10 of this paper,

were obtained in the presence of fertilizer nitrogen. The NP interaction was particularly important in maize, and to a lesser extent for sunflowers, but in groundnuts it was small. The responses of maize to N or P alone, and to these two elements together, are given in Table 3.

TABLE 3. *Effect on Maize of Nitrogen or Phosphorus applied Alone, and Together (lb. grain per acre)*

	No. of years	*No. of experiments*	*Mean yield, without N and P*	*Response to*		
				N *alone*	P *alone*	N *and* P *together*
Nachingwea						
All soils . .	4	15	1,045	276	201	680
Urambo						
Red loams .	2	4	767	395	96	646
Sands . .	2	5	1,006	282	−10	401
Kongwa						
Upland soils .	1	1	1,556	81	66	440
Valley soil .	1	1	2,325	−110	65	497

At Nachingwea there were deficiencies of both N and P, both of which gave widespread responses, although the optimum response was obtained only when they were given together. At Urambo nitrogen deficiency was paramount and this appears to have precluded a response to phosphorus unless fertilizer nitrogen was also given; with nitrogen the crop was able to benefit from additional phosphorus.

Rates of application

In a few experiments at Nachingwea and Urambo the effect on maize of different rates of application of nitrogen was determined. The results are in Table 4.

TABLE 4. *Effect of Rate of Application of Nitrogen on Maize at Nachingwea and Urambo (lb. grain per acre)*

	Nachingwea (4 experiments)	*Urambo (6 experiments)*
Yield, no added N . . .	1,330	800
Response to		
22·5 lb. N per acre . . .	181	592
45 lb. „ „ . . .	391	794

At Nachingwea, in four experiments, the mean response to the first 22·5 lb. N was 181 lb. grain, whilst the second 22·5 lb. N gave a further 210 lb. At Urambo, in six experiments, the smaller dressing increased the mean yield by almost 600 lb. grain, and the larger dressing gave a further 200 lb. The high response to the lower dressing at Urambo

demonstrates the acute nitrogen deficiency of the soils of that area. The data indicate that greater responses would have been obtained from even higher rates of application.

Time of application

In the earlier experiments ammonium sulphate was applied to the seed bed but this was found to impair germination of certain crops, particularly sunflower, very seriously. The effect on germination of maize was not serious but the response obtained from seed bed application was not as great as that from a side-dressing applied about 4 to 6 weeks after planting. Data from three experiments at Urambo comparing the two times of application are given in Table 5.

TABLE 5. *Comparison of Seed-bed Application and Top-dressed Nitrogen for Maize in Three experiments at Urambo (lb. grain per acre)*

	Seed bed	*Top dressed*
Yield, no added N . . .	873	
Response to		
22·5 lb. N per acre . . .	189	110
45 lb. N „ „ . . .	66	274
67·5 lb. N „ „ . . .	109	384

Sulphur

In recent years attention has been drawn by Beauchamp [10] to the possibility of widespread sulphur deficiency in the soils of East Africa. In West Africa Greenwood [11] and Nye [12] have examined the part sulphur plays in responses given by groundnuts to ammonium sulphate and single superphosphate. Nye's experiments suggest that groundnuts are particularly sensitive to sulphur deficiency and he suggests that this is connected with the efficiency of the root-nodules.

None of the Tanganyika experiments discussed in this paper was specifically designed to measure the response to sulphur but groundnut experiments of three types can be used to give information on this point.

Gypsum experiments. The effect of gypsum on groundnuts was investigated in 1947–8, in view of the improved yields obtained from gypsum in the southern United States [13]. The mean yield in seven experiments at Kongwa was 612 lb. kernels per acre. There was no overall effect of gypsum which supplied 50 lb. sulphur per acre. In individual experiments the response varied from −53 to +40 lb. kernels per acre. In one experiment at Urambo, on a grey sand, the yield with gypsum was raised by only 50 lb., from 780 to 830 lb. kernels per acre. In these experiments phosphorus was given to all plots as ammonium phosphate. In view of the consistency of these results no further experiments were designed to determine the effect of gypsum.

Comparison of single and 'triple' superphosphate. In 1950 single and 'triple' superphosphate were compared in the absence of ammonium

sulphate. Both types of superphosphate were applied at rates which supplied 20 lb. P per acre. The single superphosphate supplied about 25 lb. S per acre, whilst the 'triple' superphosphate supplied about one-tenth of this amount of sulphur. The yield data are given in Table 6.

TABLE 6. *Effect on Groundnuts of Single and 'Triple' Superphosphate in the Absence of other Fertilizer containing Sulphur (lb. kernels per acre)*

	Nachingwea	*Urambo*		*Kongwa*
	All soils	*Red loams*	*Grey sands*	*Upland soils*
No. of experiments .	2	2	2	2
Yield, no added fertilizer	795	856	916	938
Response to:				
Single superphosphate	155	64	34	112
'Triple' superphosphate	212	144	86	48

At Nachingwea, where responses were large, and at Urambo, the response to 'triple' superphosphate was greater than that to the single form. At Kongwa single gave a higher response than 'triple' superphosphate but the experiments with gypsum already described suggest that the greater response to single superphosphate was not due to its higher sulphur content.

Responses to ammonium sulphate in absence of other sulphur sources. The response of groundnuts to ammonium sulphate when phosphorus was also given has been presented in Table 2. In some of these experiments 'triple', and in others single, superphosphate was used, so that a possible sulphur effect may be masked. The response to ammonium sulphate in the absence of either of the superphosphates or any other fertilizer which may have supplied sulphur is given in Table 7. The ammonium

TABLE 7. *Effect of Ammonium Sulphate in the Absence of Other Fertilizers containing Sulphur, on Groundnuts (lb. kernels per acre)*

	No. of experiments	*Mean yield, without ammonium sulphate*	*Mean response to ammonium sulphate*	*% response*
Nachingwea, all soils .	17	894	34	4
Urambo, red loams .	2	772	12	2
grey sands .	3	736	99	13
Kongwa, upland soils .	12	613	28	5
valley soils .	6	508	26	5

sulphate supplied 13 lb. S per acre. At Nachingwea and Kongwa the mean response to ammonium sulphate was small. At Urambo the mean response of 99 lb., given by three experiments on the sands, is largely accounted for by one of these experiments in which the response was over 220 lb.

In two additional experiments at Nachingwea, in which 75 lb. S per acre was given as ammonium sulphate, the response was about 40 lb. kernels per acre in each case.

As a whole, the evidence indicates that lack of sulphur did not limit yield of groundnuts in any of the areas, and so it is unlikely that other crops suffered from sulphur deficiency.

Phosphorus

Data on the response to phosphorus, derived from 179 experiments, are presented in Table 8. The rate of application was 25 lb. P per acre, and in view of the importance of nitrogen for non-legumes, the responses presented for these crops are those obtained in the presence of 45 lb. N

TABLE 8. *Effect of 25 lb. Phosphorus as Single or 'Triple' Superphosphate. (For Groundnuts and Soya, without N Fertilizer; for Other Crops with 45 lb. N per acre. lb. produce per acre)*

	No. of experiments	*Mean yield, without P*	*Mean response to P*	*% response*
Nachingwea				
All soils:				
Maize	26	1,452	461	32
Sorghum	3	1,214	166	14
Sunflowers	6	584	123	21
Groundnuts	41	957	168	18
Soya	3	446	95	21
Urambo				
Red loams:				
Maize	5	998	289	29
Groundnuts	9	636	36	6
Grey sands:				
Maize	6	1,214	153	13
Sunflowers	7	354	83	23
Groundnuts	7	858	142	17
Kongwa				
Upland soils:				
Maize	4	1,150	230	20
Sunflower	8	188	50	27
Sorghum	5	930	210	22
Castor	1	522	27	5
Groundnuts	32	549	92	17
Valley soils:				
Maize	1	2,215	607	27
Sunflower	7	541	59	11
Sorghum	1	610	244	40
Safflower	1	460	45	10
Groundnuts	9	555	43	8

per acre as sulphate of ammonia. For legumes the responses given in Table 8 were obtained in the absence of fertilizer nitrogen.

At Nachingwea, the percentage response with groundnuts was 18,

with sunflower and soya 21, whilst maize gave a mean percentage response of 32. Sorghum, in three experiments, was less responsive. At Urambo percentage response with maize was high, 29, on the red loams but only about half this on the sands. With groundnuts, however, the greater response was on the sands, although the percentage response on both soils was considerably lower than that for maize. On the upland soils at Kongwa the percentage responses were maize 20, sorghum 22, and groundnuts 17. Percentage response with sunflower was higher, but yields were poor. On the more alkaline valley soils at Kongwa there were fewer experiments but sunflower and groundnuts gave percentage responses of about 10. Maize and sorghum, in single experiments, gave much higher responses.

Rates of application of phosphorus

Groundnuts. In none of the areas did the mean response of groundnuts to 25 lb. P per acre exceed 18 per cent. Experiments at Nachingwea on the rate of application of phosphorus indicate that the optimum dressing for groundnuts is very much lower than 25 lb. P per acre. Table 9 shows that the response given by 10 lb. P was as great as that given by two and three times this amount, whilst 5 lb. P per acre gave half the response given by 10 lb. P.

Greenwood [11], working with groundnuts in Northern Nigeria, found that 5 lb. P per acre (11 lb. P_2O_5) gave highly economic returns and Nye [12], in Ghana, obtained responses to 1 cwt. superphosphate (approximately 10 lb. P) which were almost as large as those given by twice this amount. It seems, therefore, that groundnuts are unable to make use of large applications of phosphorus.

TABLE 9. *Response of Groundnuts to Increasing Fertilizer Phosphorus as Superphosphate at Nachingwea (lb. kernels per acre)*

Year	*1950–2*	*1952*
No. of experiments .	8	4
Yield, no added P. .	892	1,037
Response to:		
5 lb. P per acre .	..	89
10 lb. ,, .	176	187
15 lb. ,, .	..	180
20 lb. ,, .	152	179
30 lb. ,, .	191	189

Maize. Maize was more responsive to higher dressings of phosphorus, as shown in Fig. 1.

In eight of the maize experiments at Nachingwea the highest rate of application was 20 lb. P per acre, and this increased yield by 436 lb. grain; at Urambo and Kongwa, and in three of the Nachingwea experiments, the greatest yield was obtained from 30 lb. P but the curves in Fig. 1 indicate that this amount of P did not give the maximum response.

Maize evidently differs from groundnuts in being able to utilize much higher applications of fertilizer phosphorus.

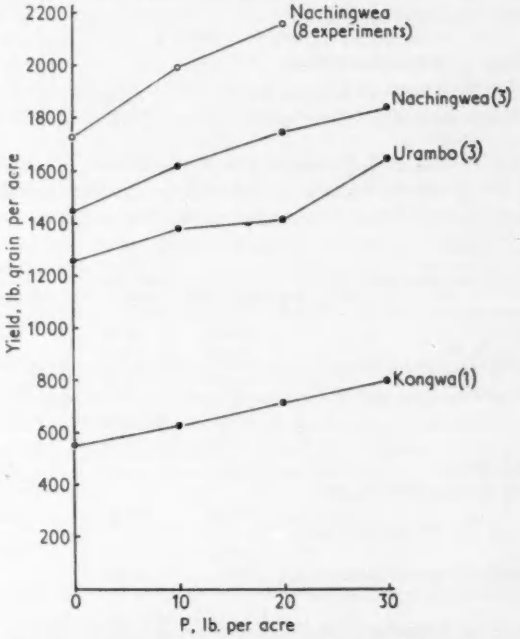


FIG. 1. Relationship between rate of application of phosphorus and yield of maize.

Phosphorus uptake of groundnuts and maize. B. Anderson and A. H. Bunting (private communication) determined at Kongwa the phosphorus uptake of a groundnut crop which yielded 900 lb. kernels per acre. The total uptake amounted to 4·0 lb. P per acre, 3·1 lb. being in the kernels. Chemical analysis of a maize crop was not carried out but data given by Sayre [14] and Weinmann [15] for maize crops in Ohio and Southern Rhodesia may be used to obtain an approximate value for the phosphorus uptake of maize for comparison with that of groundnuts. Sayre's whole-plant analysis showed that a total of 30 lb. P was removed from the soil by a crop yielding about 6,000 lb. grain per acre. Weinmann's values are lower; for crops with a mean yield of about 3,400 lb. grain the total uptake of P was 12·0 lb. per acre.

At Nachingwea in twenty-six maize experiments (Table 8) the mean yield without added P was 1,450 lb. grain per acre, for which the crop would require 5·1 lb. P on the basis of Weinmann's value, or more if Sayre's value is used. In forty-one groundnut experiments (Table 8) the mean yield without added P was 960 lb. kernels per acre, for which Anderson and Bunting's data indicate that a total uptake of 4·3 lb. P per acre would be required.

It seems, therefore, that as well as being able to use larger amounts of fertilizer phosphorus than groundnuts, as shown by the field data given above, maize also extracts rather more soil phosphorus where phosphatic fertilizer has not been applied.

Residual effect of Superphosphate

Information has been obtained on the residual value of superphosphate in the Nachingwea area. The data are presented in Table 10.

TABLE 10. *Direct and Residual Effect of Phosphorus at Nachingwea (lb. per acre kernels (groundnuts) or grain (maize))*

No. of experiments	3	1	1	1
First year	1950	1950	1952	1952
Crop	groundnuts	maize	groundnuts	soya
Yield, no added P	1,046	313	804	431
Response to 25 lb. P	371	162	212	254
Second year	1951	1951	1953	1953
Crop	maize	groundnuts	maize	maize
Yield, no added P	1,221	708	1,863	2,184
Response to 25 lb. P applied in previous year	−33	165	843	449
Response to 25 lb. P applied in second year	778	273	..	..
Response to 25 lb. P in both years	871	272	..	..

In three of four experiments laid down at Nachingwea in 1950 groundnuts were grown in the first year and were followed by maize in the second year (col. 1, Table 10); in the other experiment this order of cropping was reversed (col. 2, Table 10). In both years the responses given by phosphate applied directly to the crops were large relative to the yield. In the second year there was no residual response to phosphorus in two of the experiments in which maize was grown but in the third experiment yield was increased by 300 lb. grain per acre by the phosphorus applied in the previous year, whilst phosphorus applied directly to the crop increased yield by 540 lb. Data for the mean of these three experiments are in col. 1 of Table 10. In the experiment in which groundnuts were grown in the second year, the phosphorus applied in the first year increased yield by 165 lb., whilst direct application of phosphate gave 273 lb. kernels per acre (col. 2, Table 10).

In two experiments started in 1952 (cols. 3 and 4, Table 10) there were responses to phosphorus applied to groundnuts and soya in the first year. Unfortunately phosphate was not applied directly to the maize crop in the second year so that an estimate of the relative value of the residual phosphate cannot be made. However, the plots which had received phosphorus in the first year gave much larger yields in the second year than those which had not. A possible residual nitrogen effect of the preceding groundnut and soya crops cannot be ignored, but as

1 cwt. of ammonium sulphate per acre was given to the maize in the second year it seems likely that the increased yields were due largely to residual effects of phosphorus.

In five further experiments at Nachingwea 25 lb. P was applied in 1949 to groundnuts and to *Chloris gayana* (Rhodes Grass) which were followed by groundnuts in 1950, but no phosphate was applied in 1950 so that a comparison of the residual and direct phosphorus effects in the second year is not available. In 1949 phosphate raised the groundnut yield from 1,075 to 1,330 lb. kernels per acre. In 1950 the mean yield in plots which had received phosphate in 1949 was 910 lb. kernels per acre, whilst in those which had not the yield was 780 lb. The apparent residual effect of phosphate was of the same size whether groundnuts or *Chloris gayana* had been grown in the first year, although the yield of groundnuts following Chloris was 100 lb. more than after groundnuts. In these experiments the Chloris was not grazed. The data are given in Table 11.

TABLE 11. *Direct and Residual Responses to Phosphorus in Groundnuts (lb. kernels per acre) at Nachingwea. Mean of five experiments*

First year: 1949–50			
Crop	groundnuts	*Chloris*	Mean
Yield, no added P	1,075	..	..
Response to 25 lb. P	256	..	..
Second year: 1950–1			
Crop	groundnuts	groundnuts	
Yield, no added P	732	833	782
Response to P applied in 1949–50	126	125	125

The responses to phosphorus found in the forty-one groundnut experiments shown in Table 8 are lower than the direct responses found in the comparatively few experiments given in Tables 10 and 11. The probable reason is that the latter are less representative of the area as a whole, and indicate conditions in only two seasons.

If, as has been suggested, 10 lb. P per acre is adequate for groundnuts it might be supposed that the phosphate remaining in the soil from the 25 lb. fertilizer P applied would be adequate to give a residual response of the same order as the direct response. The finding that residual responses are considerably lower than direct responses must be due, in part at least, to the dispersal of the phosphate in the soil in the second year, in contrast with its close proximity to the seed, due to fertilizer placement, in the first year. Residual responses may also be lower due to some fixation of phosphate by the soil.

Types of phosphatic fertilizer. Concurrently with the general investigation of response to phosphorus, a series of experiments was conducted in which twelve phosphatic fertilizers were compared with single superphosphate.

The materials with their total, water-soluble and 2 per cent.-citric-acid-soluble P_2O_5 contents, are shown in Table 12. The single and

TABLE. 12. *Composition of Phosphatic Fertilizers*

	Total P_2O_5 %	*Water-soluble* P_2O_5 %	*Citric-soluble* P_2O_5 %	*Water-soluble as % of total* P_2O_5	*Citric-soluble as % of total* P_2O_5
Single superphosphate	21·5	18·6	20·1	86	93
'Triple' superphosphate	45·2	37·2	41·8	82	92
Dicalcium phosphate	43·7	1·0	38·2	2	87
Fused tricalcium phosphate	25·0	0·2	17·4	1	70
Calcium metaphosphate	57·6	9·0	13·4	16	23
Silicophosphate (ex U.K.)	31·6	0·3	26·9	1	85
Soda phosphate (ex Kenya)	19·7	0·3	16·9	2	86
Basic slag	14·6	0·0	14·4	0	99
Saphos rock (Egypt)	26·2	0·0	15·2	0	39
Gafsa rock	27·3	0·0	10·4	0	38
Christmas Island rock	37·7	0·5	11·3	0	30
Uganda rock	24·5	0·0	4·1	0	17
Seychelles Guano	24·5	0·2	12·4	1	51

'triple' superphosphates were standard commercial materials; dicalcium phosphate came from Belgium and the fused tricalcium phosphate and calcium metaphosphate were supplied by the Tennessee Valley Authority; the silicophosphate was made by the United Kingdom Ministry of Supply and the sodaphosphate was prepared from Uganda rock by the East African Industrial Research Board; the basic slag was a product of the Bessemer process. Ground rock phosphates were from Gafsa, North Africa, Egypt (Saphos), Christmas Island, and Tororo, Uganda. Guano came from the Seychelles Islands. The 'triple' superphosphate was granular but all the other materials were in powder form.

All fertilizers were applied by placement at rates which would give 20 lb. total P per acre. The data for individual experiments are given in Table 13. Experiments in which the response to superphosphate was less than 20 per cent. of the yield without fertilizer have been excluded, so that the data presented are from responsive sites only. The yields without fertilizer and the response to single superphosphate are given in lb. produce per acre. The responses to other materials are expressed as a percentage of the response to single superphosphate.

In all experiments responses to 'triple' were at least as good as to single superphosphate; in sunflower experiments they were rather better. None of the other materials was consistently as useful as the superphosphates although dicalcium phosphate gave good results in seven of the nine experiments; calcium meta-phosphate was useful for maize and sunflowers in four experiments on soils in the pH range 6·8 to 7·6 but in four experiments on soils of pH 4·9 to 6·2 it was poor; fused tricalcium phosphate gave high responses with groundnuts on soils of pH 4·9 and 5·8 at Nachingwea. Basic slag and soda phosphate were almost as good as superphosphate whilst silico-phosphate was better than superphosphate with groundnuts at Nachingwea and with sorghum at Kongwa on soils of pH 4·9 to 6·0; responses to these materials on soils

TABLE 13. *Comparison of Twelve Phosphatic Fertilizers with Single Superphosphate, all applied at 20 lb. P per acre*

	Groundnuts		*Sunflower*				*Maize*		*Sorghum*
	Nachingwea		*Nachingwea*		*Kongwa*		*Urambo*	*Kongwa*	*Kongwa*
Yield, no added P, lb./acre	430	1,160	484	600	286	371	339	557	930
Response to single superphosphate, lb./acre	98	312	112	122	70	138	383	158	225
Relative responses:									
Single superphosphate	100	100	100	100	100	100	100	100	100
'Triple' superphosphate	103	104	156	166	196	104	97	135	118
Dicalcium phosphate	109	88	137	156	33	81	37	148	158
Fused tricalcium phosphate	85	108	..	..	..	..	..	..	..
Calcium metaphosphate	34	51	137	128	19	111	109	216	50
Silicophosphate (ex U.K.)	157	110	24	61	49	72	32	67	166
Soda phosphate (ex Kenya)	93	89	54	9	57	48	8	80	92
Basic slag	67	131	78	−9	53	29	13	28	89
Saphos rock	47	49	17	11	71	58	−19	108	99
Gafsa rock	..	..	2	9	16	18	11	91	103
Christmas Island rock	19	45	−9	71	−19	54	−8	56	183
Uganda rock	−10	68	−16	−33	−29	47	10	33	127
Seychelles Guano	17	84	−58	−40	26	49	10	132	68
Soil pH	4·9	5·8	n.a.	7·2	6·2	7·3	6·8	7·6	6·0

of higher pH were poor. The rock phosphates and Seychelles guano were generally inferior to the superphosphates except in a single sorghum experiment at Kongwa in which most of the materials gave good responses.

When the materials are considered in relation to solubility it is evident that the water-soluble materials, the superphosphates, are the most satisfactory. In two groundnut experiments on acid soils citric-solubility of P appeared roughly to determine the response so that materials having 70 per cent. or more of total P soluble in 2 per cent. citric acid produced responses 85 per cent. or more of those to single superphosphate. No relationship between citric solubility and response was obtained in experiments with other crops, which were on soils covering a wider range of pH.

Apart from the superphosphates the only materials which might be worth further study are those which have the advantage of high P content, thus reducing transport, storage, and handling costs per unit of P. In particular dicalcium phosphate (44 per cent. total P_2O_5) appears to be satisfactory, and also calcium metaphosphate (60 per cent. P_2O_5) for neutral or slightly alkaline soils.

Response to fertilizer in relation to soil phosphorus

An extremely rapid method for the determination of soil phosphorus was used, in which the soil was shaken for 3 minutes with 0·3 N hydrochloric acid, and the phosphorus in the extract determined as molybdenum blue. Table 14 gives the distribution of soils in the three areas, grouped according to the P analyses of samples taken from field experiments.

TABLE 14. *Distribution of Soils According to their* 0·3 N HCl-*soluble* P *Content*

	Nachingwea	*Urambo*		*Kongwa*	
Soil P, *p.p.m.*	*All soils*	*Red loams*	*Sands*	*Upland soils*	*Valley soils*
up to 1·0 . .	11	0	1	10	0
1·1–2·0 . .	12	2	0	16	3
2·1–3·0 . .	2	3	1	8	4
3·1–4·0 . .	2	0	2	7	3
4·1–5·0 . .	0	1	3	4	1
over 5·0 . .	3	10	17	7	10
Total . .	30	16	24	52	21

The P-analysis values are low for the soils at Nachingwea and for the Upland soils at Kongwa.

The relationship between extracted soil phosphorus and response to phosphorus, of groundnuts, was investigated for each area separately. For Nachingwea this is presented in Table 15. At Kongwa the unreliability of the rainfall led to poor yields in many experiments, so that a consistent relation between extracted soil phosphorus and response to

fertilizer could not be expected, and was not found. At Urambo the values of extracted soil phosphorus were high and no relationship was found.

TABLE 15. *Relation between Soil Phosphorus extracted with* 0·3 N HCl *and Response to Fertilizer Phosphorus, with Groundnuts (lb. kernels per acre) at Nachingwea*

Soil P *p.p.m.*	*No. of experiments*	*Yield, no added* P	*Response to 25 lb.* P *per acre*	% *response*
< 0·5	7	1,079	295	27
0·5–1·0	3	1,069	195	18
1·1–1·5	8	804	143	18
1·6–2·0	4	722	122	17
> 2·0	6	1,128	120	11

In Fig. 2 the response in groundnuts is plotted against extracted soil phosphorus for the experiments at Nachingwea and Urambo. In most of the experiments at Nachingwea the soil phosphorus value was less than 2 p.p.m. In experiments in which the extracted soil phosphorus value was less than 1 p.p.m. the response was, with two exceptions, greater than 200 lb. kernels per acre; for values below 2 p.p.m. the response was greater than 100 lb. per acre.

In all experiments at Urambo the soil contained more than 2 p.p.m. extractable phosphorus and the response in all but four experiments was less than 100 lb. kernels per acre. The four experiments were on grey sands which, as Hagenzieker [9] has shown, have a very poor subsoil, but are relatively well supplied with phosphorus in the surface layers. In these circumstances a surface soil sample may be misleading, and may account for the anomalous values in Fig. 2.

In general, the data for the two areas suggest that in soils with more than 2 p.p.m. phosphorus extractable by the method used, the response of groundnuts is likely to be small.

The curve in Fig. 2 represents the regression of response in lb. kernels per acre (Y) on the logarithm of extracted soil phosphorus (X) for all soils at Nachingwea and the red soils at Urambo. The sands at Urambo have been omitted from the calculation of the regression.

The regression equation, which is highly significant, is

$$Y = 182 - 174 \log_{10} X \; (t = 3{\cdot}44; \text{for P} = 0{\cdot}01, t = 2{\cdot}73).$$

Soil phosphorus was determined in too few maize experiments to permit estimation of its relationship with crop response but in five experiments at Nachingwea the extracted soil phosphorus was less than 1·5 p.p.m. in all cases, whilst at Urambo, in nine experiments, all soils had more than 5 p.p.m. The mean response to 25 lb. P was 510 lb. grain per acre at Nachingwea and 230 lb. at Urambo. The mean yields without fertilizer were 840 and 990 lb. at Nachingwea and Urambo respectively.

In view of Birch's findings [16] that an inverse relationship existed between soil pH and percentage response to phosphorus for wheat, millet,

and grass on acid soils in Kenya, the possibility of a similar relationship for groundnuts was investigated. No such relationship was found for either percentage response or absolute response at Nachingwea where, in twenty-three experiments, there was good cover of the pH range 4·4 to 6·5. At Urambo the soil pH in fourteen experiments lay between 6·1 and 8·2: there was no relationship between pH and response to superphosphate.

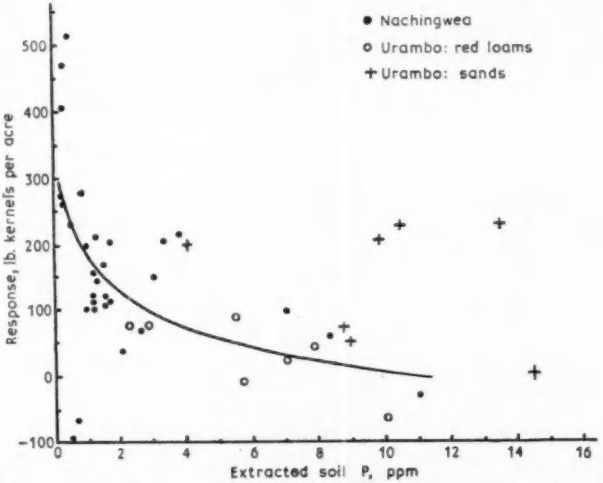


FIG. 2. Relationship between soil phosphorus extracted by dilute hydrochloric acid and yield response of groundnuts.

Potassium

The effect of potassium (56 lb. K per acre) was determined in eighty-four experiments. Responses were generally small and it is concluded that for most crops the soils in all areas contain adequate amounts of potassium. Tobacco, however, is an exception in requiring unusually large amounts of potassium, particularly for the production of high-quality leaf.

Special requirements of tobacco. An experiment on flue-cured Virginia tobacco was conducted on a typical grey coarse sand at Urambo during the 1950–1 crop season. The data, which have been more fully reported by Bunting [17], are summarized in Table 16.

TABLE 16. *Mean Yields of Cured Tobacco Leaf, lb. per acre*

N *applied lb./acre*	*Yield*	P *applied, lb./acre*	*Yield*	K *applied, lb./acre*	*Yield*
0	0	0	578	0	0
11	560	10	693	18	601
22	668	20	646	36	655
44	724	40	687	72	700

Nitrogen and potassium applications were essential for the production of curable leaf but dressings beyond 11 and 18 lb. per acre respectively gave relatively small increases in yield. Phosphorus was not essential but 10 lb. per acre increased yield of cured leaf by about 100 lb. per acre. There was no further increase from greater amounts of phosphorus.

Leaf quality was lowered by increasing nitrogen, but it was improved by potassium, which offset the nitrogen effect. The nitrogen-potassium balance was therefore important. Phosphorus had no effect on quality.

In a further experiment at Urambo, Anderson [18] reports that tobacco showed deficiency symptoms when less than 37 lb. K per acre was given. Dressings above this and up to 112 lb. K. per acre were satisfactory whether given at planting or as top dressing.

These two experiments demonstrate a peculiarity of the tobacco plant, which has a high potassium requirement, rather than a general soil potassium deficiency, since no other crop has shown a response to potassium on the sands at Urambo or on any soil elsewhere in the three areas.

Calcium

The effect of 8 cwt. of ground limestone was determined in ninety-eight experiments. In most of these, in all areas, the effect was small but negative. Only on the Mtanana soils at Kongwa was there a large positive response to limestone.

Mtanana soils at Kongwa. These soils are discussed by Muir, Anderson, and Stephen [6]. Briefly, they are acid (pH 4·1–6·0) and low in exchangeable calcium, and are poorly drained. They were first cropped extensively in 1950 when the yield of groundnuts in two experiments was good, but maize, sunflower, castor, safflower, and niger oil gave very poor yields, although in certain experiments growth appeared to be improved by limestone.

Analysis of dried leaves of sunflower plants showed that healthy plants contained less manganese than those of stunted plants (200 p.p.m. and 550 p.p.m. Mn respectively) but more calcium (1·2 and 0·74 per cent. respectively). Iron and magnesium were present in slightly larger amounts in the stunted than in the healthy plants.

Experiments in pots confirmed the beneficial effect of limestone on the germination and establishment of sunflowers, maize, and sorghum, but not of groundnuts.

In 1950–1 field experiments on these soils were confined to maize and the mean response to 8 cwt. limestone per acre in three experiments was over 300 lb. grain per acre.

The residual effects of limestone and phosphorus applied in 1949–50 were measured, using maize, in 1950–1. In one experiment, at Machenje, where the exchangeable soil calcium was 2·2 m.e. Ca per 100 gm. soil, the residual effect of limestone was small, being about 220 lb. grain, or 15 per cent. of the crop. The residual effect of phosphorus was also small. In the other experiment, at Mtanana, where the exchangeable soil calcium was only 1·0 m.e. Ca per 100 gm. soil, the residual effect of limestone was 480 lb. grain or 49 per cent. of the crop. Residual phosphorus doubled the yield, but only where limestone had been given. Similarly,

phosphorus applied directly to the crop in 1950–1 gave a small increase in the absence of limestone but doubled the yield in its presence. The data for these two experiments are given in Table 17.

TABLE 17. *Effect of Phosphorus and Limestone on Mtanana Soils. Maize, lb. grain per acre*, 1950–1

Site	*Machenje*		*Mtanana*	
	Limestone		*Limestone*	
Phosphorus applied, 25 lb. P per acre	*None*	*8 cwt./acre 1949–50*	*None*	*8 cwt./acre 1949–50*
	±100·5		±108·1	
None	1,610	1,626	886	690
P in 1949–50	1,694	1,868	684	1,368
P in 1950–1	1,286	1,568	1,210	1,466
P in both years	1,422	1,630	1,088	1,600
Least Significant Difference (P = 0·05)	310		333	

Discussion

The three areas in which the experiments were carried out are typical of much undeveloped land in Tanganyika, and probably of neighbouring territories also, where the soils overlie basement complex rocks but vary with climate, topography, and vegetation. The work was started with the twofold aim of determining rapidly the broad fertility characteristics of the main soil types in the three areas, and also of obtaining information on rates and methods of application of fertilizers. The first of these two objectives was largely achieved in the experiments with groundnuts and maize, supported by less precise data for other crops. The detailed exploration of the responses of individual crops to added plant nutrients was not completed although much useful information for groundnuts and maize was accumulated.

Crop characteristics. Groundnuts and maize were the most important crops in the areas at the time and were used more generally than other crops in the experiments. They appear to have been well suited as test crops for the general characterization of soil fertility in the three areas. Groundnuts responded to phosphorus on acutely deficient soils. Maize extended the range of response to soils of rather higher phosphate status, and also responded to ammonium sulphate, so that it was a suitable crop for indicating soil nitrogen status, and has demonstrated the importance of the NP interaction. Results with sorghum and sunflower were similar to those with maize.

Maize was found to differ from groundnuts in that it required a much larger application of fertilizer phosphorus to give the maximum response.

Only in a very few cases was there a response to ammonium sulphate by groundnuts. This contrasts with the results obtained by Bunting [19] at Tozi in the Blue Nile Province of the Sudan where responses of 140 lb.

kernels were obtained with 22 lb. N, and 300 lb. kernels per acre with 44 lb. N per acre, as ammonium nitrate. Further nitrogen gave small additional yield increases. In Tanganyika the rate of application was only 11 lb. N per acre in most experiments and it might be argued that this was too low to show a response. However, at Nachingwea, where nitrogen responses are large with non-legumes, no increase in yield of groundnuts was obtained with 66 lb. N per acre in two experiments designed to determine the effect of applications of nitrogen greater than the standard dressing of 11 lb. In none of the areas were nitrogen-deficiency symptoms observed in groundnuts and abundant nodules were formed on the plant roots, so that it is concluded that the nitrogen nutrition of groundnuts was generally satisfactory in all areas. None of the groundnut seed was inoculated. It seems, therefore, that even on land newly cleared from natural vegetation the specific nodule bacteria were widespread and effective in supplying the needs of the crop.

Groundnuts have proved to be a useful crop to indicate soil sulphur status and the absence of response to ammonium sulphate indicates that there was no sulphur deficiency in the areas. This is supported by the comparison of responses to single and 'triple' superphosphate and by the work with gypsum. In view of these results with groundnuts the responses to ammonium sulphate in non-legumes are considered to be due to nitrogen and not to sulphur.

Influence of some non-soil factors on yield. The general level of yield in most groundnut experiments was satisfactory, except at Kongwa in 1949 when the total rainfall was inadequate, and at Urambo in the same year owing to poor rainfall distribution and rosette disease. Sunflower yield was limited in all areas by inadequate populations of pollinators and the crop was not grown after 1950. The maize yields may have been limited by plant population levels. In most of the experiments there were between 4,000 and 10,000 plants per acre. Recently Hemingway [20] has shown at Nachingwea that the maximum yield of maize was obtained with populations between 15,000 and 30,000 plants per acre, and that there was little variation in yield within this range. Although the yields reported in the present paper may not have been maximal, the percentage responses are more likely to be under- than over-estimated, since at higher populations and higher yield levels nutrient shortages are likely to become more marked, so that greater responses might be expected.

Principal soil fertility characteristics of the three areas. The main conclusions to be drawn from the experiments at *Nachingwea* are that the soils are deficient in phosphorus for all crops, and in nitrogen for non-leguminous crops, in which the NP interaction is also important. The responses to fertilizer phosphorus in field experiments support the results of soil analysis which indicate that the phosphorus status is low throughout the area. Superphosphate appears to have a valuable residual effect with both groundnuts and maize. A one year 'rest' under *Chloris gayana*, which was not grazed, resulted in improved groundnut yields the following year.

At *Urambo* nitrogen is the most important limiting plant nutrient for

maize and sunflower, but not for groundnuts. Soil phosphate status appears to be higher at Urambo than in the other areas and responses to phosphatic fertilizer were more erratic, although large responses were obtained with maize on the red loams. Soil potassium was found to be adequate for all crops except tobacco, for which potassium fertilizer was necessary to obtain a good quality leaf.

In an experiment on a red loam at Urambo the effect of 10 tons per acre of farmyard manure and the standard rates of nitrogen and phosphorus fertilizer were examined factorially. The results are given in Table 18.

TABLE 18. *Effect of Nitrogen, Phosphorus, and Farmyard Manure on Maize (lb. grain per acre) at Urambo, 1950*

	No F.Y.M.	*F.Y.M. 10 tons/acre*
	±132·6	
No N, no P . . .	994	1,284
N alone (44 lb./acre) .	869	1,429
P alone (25 lb./acre) .	972	1,320
N and P . . .	1,429	1,755
Least Significant Difference (P = 0·05) . . .	378	

The NP interaction was large; nitrogen or phosphorus given alone had no significant effect but together they increased yield by about 450 lb. grain per acre, both in the absence and presence of farmyard manure, which itself increased yield by a mean value of 380 lb. This experiment not only indicates the importance of the NP interaction but also demonstrates, by the effect of farmyard manure, that either insufficient fertilizer nitrogen and phosphorus were applied, or that other factors were limiting, in the absence of farmyard manure. The experiment illustrates the value of including farmyard manure in an experimental programme as it often raises yields above those given by other treatments and thus provides a criterion by which they may be judged. A. C. Evans (private communication) has obtained similar results with farmyard manure at Nachingwea; similar effects and also long-term residual effects of farmyard manure have been reported by Peat [21] from the Lake Province of Tanganyika.

At *Kongwa*, when rainfall permitted good crop yields, soil phosphorus was limiting in the Upland soils and most crops responded to superphosphate; soil analysis indicates that the soil phosphorus levels are similar to those at Nachingwea. In the valley soils phosphorus status is higher and responses were small in most cases. Responses to nitrogen were generally small.

The only response to limestone in the three areas was on the acid Mtanana soils at Kongwa.

On low-lying alkaline soils of the Lubiri series at Kongwa severe chlorosis and poor growth of groundnuts was found to be due to alkali-

induced iron deficiency which could be cured by spraying with ferrous sulphate. This was the only observed case of a trace element deficiency in the three areas. Maize and sorghum were not affected and good yields of both these crops were obtained.

It is clear from the comparison of the three areas that rainfall is the dominating factor influencing response to nitrogen, but soil texture, as well as phosphorus status, is also of importance. Only in the two high-rainfall areas, Nachingwea and Urambo, was response to nitrogen important and the greatest responses were obtained on the open-textured, sandy soils at Urambo. In these soils Hagenzieker [22] has shown that during the early part of the rainy season, before rainfall is sufficient to cause leaching, there is a flush of nitrate which can be used by early planted crops so that timely planting is important. Later in the season leaching is intense and fertilizer nitrogen is necessary for high yields. Under these conditions time of application was important, and for maize 4 to 6 weeks after planting was satisfactory.

Response to superphosphate by groundnuts has been found to be inversely related to the amount of soil phosphorus extracted by dilute hydrochloric acid for soils at Nachingwea and the red loams at Urambo. The less extensive soil analysis data available for maize and sunflower experiments suggest a similar relationship for these crops also. Response to superphosphate by groundnuts and maize was independent of soil pH but for certain other phosphatic fertilizers soil pH was an important factor influencing the response. Of the thirteen phosphatic materials tested those containing a high percentage of water-soluble phosphate, single and 'triple' superphosphate, were the most satisfactory. None of the other materials was effective where superphosphate failed to give a response. In the experiments in which the superphosphates gave responses dicalcium phosphate did well in most cases. Calcium metaphosphate gave good response on the neutral soils; silicophosphate was effective on acid soils. The rock phosphates were poor, even on acid soils.

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THE SPACING OF SWAMP RICE IN TRINIDAD

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Summary

Within the limits tested the number of panicles per unit area produced by the rice varieties most commonly grown in Trinidad increased as the area allocated to hills decreased. This led to an increase in yield despite decreases in both the number of panicles produced in each hill and their weight. Further, the yield response to spacing of the hills was little modified by the pattern of distribution of the hills, the number of plants placed in each hill or the time of planting, but tillering was increased by placing more than three plants in a hill occupying an area of 324 sq. in. It is recommended that rice in Trinidad should be transplanted in hills spaced approximately 6 in. apart if family labour is used, or 8 in. if labour is hired. It is suggested that any attempt to evolve a labour-saving method of swamp rice establishment should aim at producing a population of hills each occupying about 36 sq. in. with little regard for the number of plants in each hill or the pattern of distribution of the hills. It is also suggested that the possibility of substituting direct seeding for transplanting should not be overlooked although it is recognized that many factors other than spacing must be considered.

As in many parts of the world, there is interest in Trinidad in the possibility of completely mechanizing the production of rice on a small scale typical of peasant production. If this is to be achieved some means is required for reducing the 188 man-hours of labour per acre [1] currently used, on average, to establish the crop. A logical approach to the problem is impossible without knowing what constitutes an ideal plant population in terms of both density and distribution and the effect on crop yield of variation from this ideal. The work reported below was undertaken in an effort to obtain this information.

Almost without exception, swamp rice in Trinidad is established by transplanting, and seedlings are placed in the field at distances between hills ranging from 9×9 to 18×18 in. It has been estimated that approximately half the rice growers in the Island place their seedlings at a distance of 12 in., and approximately one-third at 18 in. between hills. Any number of seedlings between three and thirteen may be placed in each hill but numbers between five and eight are most commonly used [1].

Neither the optimum spacing between hills nor the best number of seedlings to place in each hill has been made clear by previous experimental work conducted in Trinidad. Richards [2] found that decreasing the distance between hills in steps from 16 to 8 in. caused a progressive decrease in the number of panicles produced in each hill, accompanied by a decrease in the mean weight per panicle and an increase in the number of panicles produced on unit area. Yield differences between treatments were not statistically significant but he observed a downward gradient in yield from the closer to the wider spacing. Murray [3], also working in Trinidad, obtained similar results from decreasing the distance between hills, in steps, from 15 to 6 in., but also failed to obtain statisti-

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cally significant yield differences. He concluded that planting seedlings in hills about 12 in. apart and placing approximately three plants in each hill is correct for Trinidad conditions and the rice varieties normally used.

From other parts of the world further information is available. Thomestone in India [4], Rodrigo in the Philippines [5], Adair, Beachell, Jodan, Davis, and Jones in the U.S.A. [6], Takahashi and Shibusawa in Japan [7], and Haigh in Ceylon [8] have all shown that decreasing the distance between hills results in a decrease in the number of panicles produced per hill.

Adair *et al.* [6] and Takahashi and Shibusawa [7] showed a progressive increase in yield to be associated with decreasing the distance between hills, and Thomestone [4] obtained a similar yield trend as the distance between hills was decreased in steps from 15×15 to 4×4 in. Haigh [8] also obtained a similar result and showed that the response was the same on soils of high and low fertility. He inferred that the optimum spacing of the variety he used was about 3 in. between hills.

However, Rodrigo [5], Sethi and co-workers [9], Kirano, Suenaya, and Shemada [10] all obtained results which showed that highest yields were not necessarily associated with the closest spacing of hills. Rodrigo found that, from a range of treatments, intermediate spacings of 30 or 20 cm. gave highest yields for different varieties. Sethi concluded that 6 to 9 in. was the optimum from a range of 3 to 12 in. between hills, and Kirano *et al.* obtained yields twice as large from rice planted in hills spaced 24 cm. apart as from hills 18 cm. apart.

Information on the effect of the number of plants in each hill is more limited. Thomestone [4] and Calvo [11] showed a progressive increase in the number of panicles produced per hill with progressively increasing, from one to four, the number of plants per hill. Sethi [9] obtained highest yields from one, two, or four seedlings at different locations but Haigh [8] found that three plants per hill gave highest yields in hills 18, 12, or 8 in. apart, but one plant per hill gave highest yields in hills 4 in. apart.

The results obtained in other parts of the world are thus rather conflicting, which suggests that environmental factors and the variety used considerably affect the responses; the results previously obtained in Trinidad are also inconclusive. For these reasons a series of experiments was carried out, using local rice varieties, in an attempt to find the optimum spacing and pattern of distribution of hills, the optimum number of seedlings therein, and the degree of variation from these optima which can be accepted without seriously affecting yield.

Experiment 1

Seedlings were transplanted at various distances between hills, with one plant in each hill. The hills were placed in a rectangular pattern at distances apart (in inches) as follows:

5×5	6×6
8×8	10×10
12×12	15×15
16×16	20×20

Two varieties were used, Kalyaman and Joya. The experiment consisted of three replications of the sixteen treatment combinations, arranged in six blocks of eight treatments, with one degree of freedom of the interaction between spacing and the varieties confounded with the blocks. Each block was contained within a separate bund and each plot occupied 0·0092 acre.

This and subsequent experiments were located at the Imperial College of Tropical Agriculture, Trinidad, on a soil type classified by Chenery as Pasea silty clay loam to silty clay [12].

TABLE 1. *Effect on the Number of Panicles per Hill of Varying the Distance between Hills, each containing One Plant*

Distance between hills, inches	*Mean no. of panicles per hill*	
	Variety Kalyaman	*Variety Joya*
5×5	4·5	4·7
6×6	6·5	6·2
8×8	9·4	9·9
10×10	10·1	11·2
12×12	15·8	16·5
15×15	15·6	18·0
16×16	20·7	19·7
20×20	22·6	27·0
Mean	13·2	14·2

The two varieties received identical treatment in the nursery and were transplanted when 4½ weeks old in plots previously ploughed and puddled while submerged beneath 2–3 in. of water. Marked bamboo rods were used to ensure correct spacing of the plants. The few plants which died during the first week after transplanting were replaced from the nursery. Water control was good and no hand-weeding was required.

Establishment of the seedlings was rapid and was not influenced by population density, but at 4 weeks after transplanting a yellowing of all plants closer than 12 in. apart was noted, which persisted until approximately 7 weeks after transplanting, but thereafter gradually disappeared until it was no longer visible by the time flowering was complete. Similar colour differences were observed in all subsequent experiments.

A few days before harvest, four plants were selected at random in each plot and the number of panicles counted. The mean numbers of panicles per plant, for each variety at each spacing, are shown in Table 1.

Both varieties matured at the same time but plots planted with rice spaced 5, 6, or 8 in. apart matured approximately 3 days before those containing rice spaced 10 or 12 in. apart which, in turn, ripened 5 to 6 days before those spaced 15, 16, or 20 in. apart. Signs of lodging were negligible but this was almost certainly due to the ideal conditions which prevailed, as both the varieties used lodge quite commonly when planted by farmers.

One row around the outside of each plot was discarded before harvesting. The discard rows occupied different areas, and the area harvested, therefore, varied with treatment. For this reason the yields of sun-dried unmilled rice have been expressed in terms of yield per 0·01 acre in Table 2.

The responses to the spacing treatments, in terms of panicles per hill and yield per acre as means of the two varieties, are shown graphically in Fig. 1. The trends of the responses are of considerable interest. The linear regression functions are significant at P = 0·01 in both instances

TABLE 2. *Effect on Yield of Sun-dried Unmilled Rice of varying the Spacing of Hills each containing One Plant*

Distance between hills, inches	*Mean yield in lb./0·01 acre*	
	Variety Kalyaman	*Variety Joya*
5×5	49·6	57·0
6×6	51·6	51·6
8×8	52·0	43·6
10×10	47·0	33·6
12×12	38·3	31·3
15×15	34·0	39·3
16×16	39·3	33·0
20×20	34·3	31·3
Mean	43·3	40·1

and are shown as dotted lines. These regressions serve to emphasize the inter-dependence of the variables and demonstrate the presence of an appreciable linear component in the response curves. It is not inferred, however, that the response curves are strictly linear and, indeed, this is considered to be highly unlikely.

No significant differences between the two varieties were found, in either the number of panicles produced per plant or the yield per unit area, and the interactions between the varieties and spacing also proved to be without significance.

Experiment 2

To permit a more precise study of the response of rice to variation of the distance between hills each containing one plant, small groups each consisting of forty-nine transplants of the variety D52-37 were planted, the hills being at the following distances apart (in inches):

5×5	8×8	12×12
14×14	17×17	20×20

The differently spaced groups were distributed at random within small areas bounded by a water-retaining bund and the spaces between the groups were planted with rice which did not form part of the trial.

Three such areas were planted on 2 July, 29 July, and 26 August, respectively, representing early, normal, and late planting in Trinidad.

The seedlings were 4½ weeks old at transplanting. Irrigation water was provided by pumping and all plots were hand-weeded as required.

The areas transplanted on 2 July, 29 July, and 26 August were harvested between 9–17 November, 24–30 November, and 6–10 December, respectively. No plants were harvested from the group spaced at 12 × 12 which was planted on 2 July, or from the group spaced at 5 × 5 which

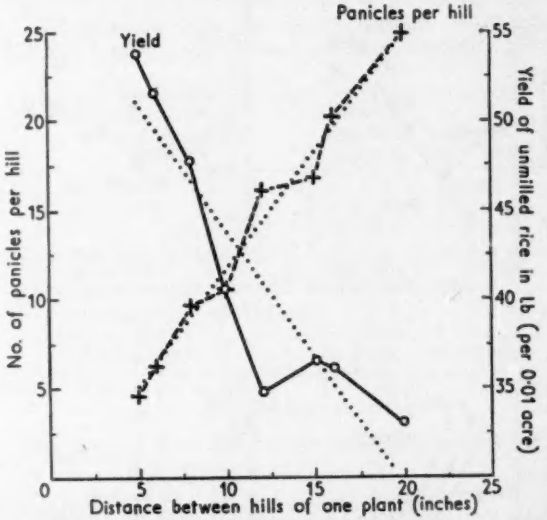

FIG. 1. No. of panicles per hill and yield of unmilled rice, plotted against distance between the hills. Mean of two varieties. Linear regression shown by dotted lines.

Regression of panicles per hill = +1·326 (significant at P = 0·01)
" " yield " " = −1·409 (" " ")

Least Significant Differences

	P = 0·05	P = 0·01
No. of panicles per hill	3·56	4·81
Yield in lb. " "	7·94	10·70

was planted on 29 July, both of which suffered serious physical damage during a storm, lodged badly before flowering, and failed to recover.

Only plants correctly spaced in relation to all their neighbours were harvested and where a plant was missing all those immediately surrounding the gap were also rejected. Some of the plants in the earliest-planted area suffered damage from birds and were rejected but, where the damaged culms represented 10 per cent. of the total or less, the plant was accepted and the mean culm weight estimated from the undamaged culms.

Each plant was harvested separately by removing complete panicles which were both counted and weighed. The mean proportion of grain in these panicles varied between the limits of 95·3 per cent. for those whose total weight fell between 7·500 and 8·499 gm. and 93·5 per cent. for those whose total weight fell between 2·500 and 3·499 gm. The

estimates of yield per square foot obtained from this experiment are thus slightly biased in favour of close planting.

Fig. 2 shows graphically the estimated mean panicle weight for each of the different treatments (*b*) and the estimated mean number of panicles per plant (*a*), both of which were directly observed variables. The esti-

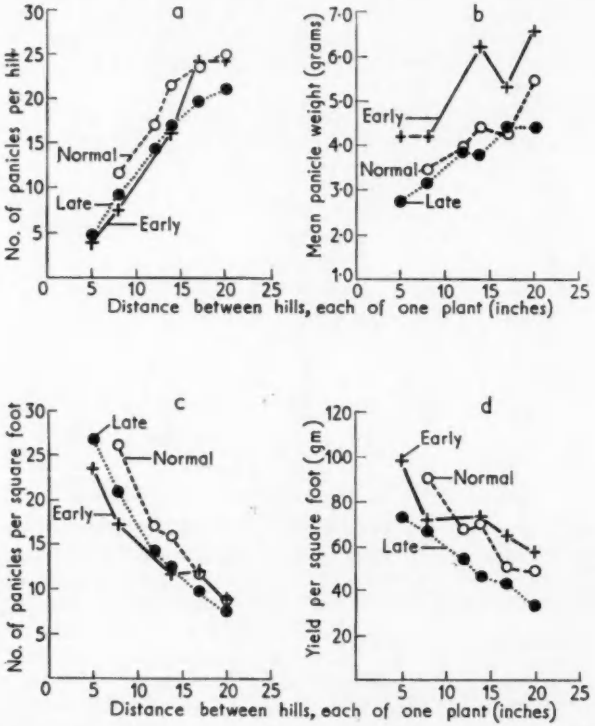

FIG. 2. (*a*) No. of panicles per plant; (*b*) mean panicle weight; (*c*) no. of panicles per square foot; (*d*) yield per square foot, each plotted against distance between hills for three different planting times.

Early: transplanted 2 July
Normal: transplanted 29 July
Late: transplanted 26 August.

mated means of the number of mature panicles per square foot, and the estimates of the mean yield per square foot, which have been calculated from (*a*) and (*b*), are also shown at (*c*) and (*d*) in Fig. 1.

From this figure it is clear that, irrespective of time of planting, there was a systematic decrease in the number of panicles produced at each hill as the distance between the hills decreased, accompanied by a steady decrease in the mean weight of the panicles. The highest numbers of panicles per unit area and the highest yields are associated with the

closest spacing of the hills. The relationship between the spacing of the hills and the number of panicles produced at each hill has been confirmed by calculation of the linear regression functions, which are all statistically significant. The regressions of the mean panicle weights on variation of the distance between hills also proved to be significant for all times of planting. Statistical significance of the regression function is taken as evidence of the interdependence of the variables but it is not inferred that the relationships are strictly linear. The values of the regression functions and their various levels of significance are shown below:

Dependent variable affected by spacing of hills	*Value of regression coefficient*	*Level of significance*
Rice transplanted on 2 July		
Panicle weight . . .	+0·1577	P = 0·05
Panicles per plant . .	+1·480	P = 0·01
Rice transplanted on 29 July		
Panicle weight . . .	+0·1504	P = 0·05
Panicles per plant . .	+1·147	P = 0·01
Rice transplanted on 26 August		
Panicle weight . . .	+0·1154	P = 0·01
Panicles per plant . .	+1·124	P = 0·01

Experiment 3

A third experiment was conducted to find the response of rice to the variation of factors of four types:

(i) Area per hill; 36, 144, or 324 square inches.
(ii) Pattern of planting; rectangles with side ratios of 1 to 1, 2·25 to 1, or 4 to 1.
(iii) Number of plants in each hill; one, three, or six.
(iv) Variety; D52-37, D110, or Kalyaman.

The eighty-one treatment combinations were used in a single replicate of a 3^4 factorial design arranged in blocks of nine plots with complete confounding of the four-factor interactions with the blocks. All the three- and four-factor interactions were used to obtain an estimate of error in the analysis of variance. The varietal comparison was included to obtain information on the interactions with the other factors.

The experiment was planted between 2 August and 11 August, using methods similar to those already described except that no replacements were made of plants which died. Each plot occupied 0·0143 acre.

After the removal of guard-rows around each plot the crop was harvested between 19 November and 5 December. The variety D52-37 was the first to ripen followed quickly by D110 with the variety Kalyaman some 10 days later. It was also observed that the closest-spaced plants matured approximately 7 days earlier than the most widely-spaced plants of the same variety. The varieties D52-37 and D110, which have very weak straw, lodged severely on all plots. The variety Kalyaman also lodged, but less severely in those plots in which the hills were each allocated 144 or 324 square inches.

A few days before harvesting four plants were sampled at random from each plot to obtain an estimate of the number of panicles produced in each hill. The estimated plot means of the number of panicles per hill are shown in Table 3.

TABLE 3. *Estimated Means of the Number of Panicles per Hill*

Variety	*No. of plants per hill*	36 *sq. in. per hill* *Side ratio* 1:1	2·25:1	4:1	144 *sq. in. per hill* *Side ratio* 1:1	2·25:1	4:1	324 *sq. in. per hill* *Side ratio* 1:1	2·25:1	4:1	*Totals*
D110	1	5·8	7·3	6·5	16·8	17·5	10·8	24·5	20·8	16·5	126·5
	3	6·5	7·0	7·8	14·5	23·8	14·3	19·5	25·3	24·5	143·2
	6	4·8	7·8	6·7*	14·3	14·8	13·5	28·5	23·3	21·5	135·2
Total		17·1	22·1	21·0	45·6	56·1	38·6	72·5	69·4	62·5	
D52-37	1	6·8	4·3	9·8	12·3	12·3	20·0	21·8	20·5	16·2	124·0
	3	4·8	16·7	8·5	15·0	17·3	15·0	20·5	19·5	21·5	138·8
	6	6·5	5·5	7·0	18·2	12·5	12·3	27·8	24·0	24·8	138·6
Total		18·1	26·5	25·3	45·5	42·1	47·3	70·1	64·0	62·5	
Kalyaman	1	9·5	7·8	5·8	20·0	15·3	14·8	25·5	19·3	25·3	143·3
	3	6·5	8·0	8·3	18·8	16·3	22·8	28·8	29·8	26·0	165·3
	6	5·5	5·3	5·0	13·8	16·0	17·8	30·3	31·2	25·3	150·2
Total		21·5	21·1	19·1	52·6	47·6	55·4	84·6	80·3	76·6	

* Value calculated from missing-plot formula.

TABLE 4. *Yield of sun-dried Unmilled Rice in lb. per* 0·01 *acre*

Variety	*No. of plants per hill*	36 *sq. in. per hill* *Side ratio* 1:1	2·25:1	4:1	144 *sq. in. per hill* *Side ratio* 1:1	2·25:1	4:1	324 *sq. in. per hill* *Side ratio* 1:1	2·25:1	4:1	*Totals*
D110	1	31	28	46	33	32	24	20	19	15	248
	3	30	38	40	26	23	27	22	27	18	251
	6	26	31	39*	41	34	34	18	25	16	264
Total		87	97	125	100	89	85	60	71	49	
D52-37	1	47	35	25	31	26	29	30	25	12	260
	3	42	36	27	37	30	43	26	21	31	293
	6	40	29	40	51	24	14	20	33	32	283
Total		129	100	92	119	80	86	76	79	75	
Kalyaman	1	38	23	42	36	30	34	36	10	32	281
	3	30	38	44	31	27	31	22	43	25	291
	6	40	36	40	36	33	30	29	30	27	301
Total		108	97	126	103	90	95	87	83	84	

* Value calculated from missing-plot formula.

After harvesting and threshing, the weights of sun-dried unmilled rice obtained from each plot were expressed in terms of yield per 0·01 acre and are shown in Table 4.

At the time of flowering it became obvious that an error had been made in the variety used in one of the plots. Appropriate values for the number of panicles per hill and the yield per unit area were therefore

calculated from a missing-plot formula and used in the analyses. The number of degrees of freedom used in calculating the error variance was reduced in the usual way.

The figures below have been calculated from Tables 3 and 4 and show, once again, the pronounced response of the rice to variation of the area allocated to each hill.

Area per hill (sq. in.)		36	144	324
Mean yield in lb. per 0·01 acre		35·6	31·4	24·6
Mean no. of panicles per hill		7·1	16·0	23·8
			P = 0·05	P = 0·01
Least Significant Difference	Mean yields, lb. . .		3·78	5·10
	No. of panicles per hill		1·49	2·01

The mean yield obtained from plots planted with rice allocated 36 sq. in. per hill is higher than that obtained from plots planted with rice allocated 144 sq. in. per hill at the P = 0·05 level of significance. Both remaining yield differences are significant at the P = 0·01 level. All differences between pairs of means of nos. of panicles per hill are significant at the P = 0·01 level.

None of the remaining main treatments or two-factor interactions produced effects on yield of sufficient magnitude to reach statistical significance at P = 0·05 although the difference between the varieties approached this level.

The effect of treatments other than hill spacing, on the number of panicles produced in each hill was more marked, as shown by the figures below which have been extracted from Table 3.

Variety	D52–37	D110	Kalyaman
Mean no. of panicles per hill	14·9	15·0	17·0

Least Significant Difference, 1·48 at P = 0·05; 1·97 at P = 0·01.

These figures show that the tillering of the variety Kalyaman differed significantly (P = 0·01) from that of the other two varieties.

There is also evidence of a tillering response to the number of plants placed in each hill, as shown below:

No. of plants per hill	1	3	6
Mean no. of panicles per hill	14·6	16·6	15·7

Least Significant Difference, 1·48 at P = 0·05; 1·97 at P = 0·01.

These figures show, therefore, that significantly more panicles have been produced as a result of placing three plants in each hill rather than one (P = 0·01) but that none of the other differences between the means is significant.

The interaction between the area per hill and the number of plants placed in each hill is also marked; the mean numbers of panicles per hill for different treatment combinations are shown below:

	36 sq. in. per hill	*144 sq. in. per hill*	*324 sq. in. per hill*
One plant per hill	7·1	15·5	21·2
Three plants per hill	8·2	17·5	23·9
Six plants per hill	6·0	14·8	26·3

Least Significant Difference, 2·58 at P=0·05; 3·48 at P=0·01.

A change from three to six plants per hill thus caused an increase in the number of panicles produced in hills each occupying an area of 324 square inches but decreased the number of panicles produced in hills occupying only 36 or 144 square inches. These differences in response are significant ($P = 0.01$).

The effect, on the number of panicles per hill, of the interaction between the area allocated to each hill and the variety is also significant; the responses are shown below:

	36 *sq. in. per hill*	144 *sq. in. per hill*	324 *sq. in. per hill*
Kalyaman . .	6·9	17·3	26·8
D110 . . .	6·7	15·6	22·7
D52-37 . . .	7·8	15·0	21·8

Least Significant Difference, 2·58 at $P = 0.05$; 3·48 at $P = 0.01$.

These data show that the tillering response of the variety D52-37 to a change from 36 to 144 sq. in. per hill differs significantly ($P = 0.05$) from the tillering response of Kalyaman to the same change, and these two varieties show significantly different tillering responses ($P = 0.05$) to the change from 144 sq. in. to 324 sq. in. Also, both D52-37 and D110 have responded significantly less than Kalyaman ($P = 0.01$) to changes from 36 to 324 sq. in.

Discussion

The Effect of Treatments on Yield

The results of all these experiments show that, within the limits tested, the yield of rice was increased by reducing the distance between hills, even though both the weight and the number of panicles produced in each hill were reduced. This finding applies to all the varieties tested. Information obtained from Experiment 2 also shows that this effect is not modified by planting either 1 month earlier or 1 month later than is normal for Trinidad and the results from Experiment 3 show that the number of plants placed in each hill and the pattern of distribution of the hills had no detectable effect on yield.

The Effect of Treatments on Tillering

The results from all three experiments show that the number of panicles produced in each hill was decreased as the distance between hills was decreased. The information obtained from Experiment 2 also shows that the mean panicle weight decreased but the number of panicles produced on unit land area increased as the area allocated to the hills was decreased. The results from Experiment 3 show that the tillering responses of the three varieties to variation of the space allocated to the hills were similar in trend but differed in magnitude and also that the use of up to three plants per hill can be recommended irrespective of the spacing of the hills, but placing six plants in each hill can be recommended only for hills spaced at least 18 in. apart. The different patterns of distribution of the hills produced no significant effects on the

number of panicles produced in each hill, either alone or when interacting with other treatments.

These tillering responses show that plant activity was modified by certain treatments which had no apparent effect on yield and this suggests that small yield responses probably occurred which remained undetected owing to insufficient sensitivity in the experiment.

Conclusions

The results obtained agree closely with those of Haigh [8] and also with those of Kanda and Kakizaki [13] and Girardot [14]. They also agree, in general, with the results previously obtained in Trinidad by Richards [2] and Murray [3], but whereas neither of these workers obtained appreciable responses to changes in the spacing of hills, such effects were most marked in these experiments. It is quite clear that increased yields of rice can be obtained in Trinidad by placing hills much closer together than the 12×12 to 18×18 in. commonly used. The optimum spacing cannot be accurately specified from the results obtained; whilst information on the problem of lodging at very close spacing is lacking, a distance between hills of about 6 in. can be recommended as a means of obtaining highest yields from the variety Joya which is used by about 90 per cent. of rice growers in the island. The spacing at which highest economic returns will be obtained will depend upon the relative prices of rice and labour at any particular time and upon the relative proportions of 'family' and hired labour used. By means of a rather crude estimation from the results of Experiments 1 and 2, and from the probable costs of planting at different spacings between hills, it can be shown that, at present prices, highest profits can be obtained by planting in hills spaced anything from 12 to 8 in. apart, if the transplanting is carried out entirely by hired labour. The economy of the island would be better served by planting at the closer spacing. Where 'family' labour is used planting at a distance of 6 in. between hills can be recommended since labour costs are not involved.

The results of these experiments also show that the use of more than three plants in each hill is not justified if the hills are placed 12 in. apart or less, and that even at wider spacing the benefits which will accrue from using more than three plants in a hill will be small.

Since high rice yields are associated with dense plant populations, and since the number of plants placed in each hill and the distribution of the hills had very little effect on yield, an argument can be developed in favour of direct seeding rather than transplanting, on the grounds that it is easier to establish dense populations by such means. Such an argument requires development with great circumspection, since:

(*a*) it presupposes that the results obtained with transplanted rice will hold good for rice directly seeded; and

(*b*) it overlooks the fact that a large number of interacting factors other than the density and distribution of the hills are involved.

Nevertheless, in any serious attempt to reduce the labour required to establish peasant-grown rice, due consideration must be given to the possibility of substituting direct seeding for transplanting.

Even if it is assumed that the combined advantages of transplanting are so great that direct seeding is unlikely to prove an adequate substitute, it is, nevertheless, plain from these results that efforts to evolve a labour-saving system of transplanting should be aimed at providing a means of establishing a relatively dense population of transplants in hills each occupying about 36 sq. in. or less. The pattern of distribution of the hills and the number of plants in each can be varied throughout relatively wide limits without appreciably affecting yield.

Throughout these experiments it was observed that rice transplanted in hills spaced about 8 in. apart or closer showed signs of yellowing, thought to be caused by nutrient deficiency. This suggests that by applying fertilizers to closely planted crops, yields might be further improved, and work on this subject is required.

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THE EFFECT OF BARIUM CHLORIDE AND CALCIUM SULPHATE IN HINDERING SELENIUM ABSORPTION BY LUCERNE

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Summary

An investigation was undertaken to find how to interfere with the uptake of excessive quantities of selenium by plants from seleniferous soils.

A greenhouse experiment was carried out to study the absorption of selenium by lucerne from two soils, containing 0·5 and 4·0 p.p.m. selenium. The plants grown on these soils contained from 1·6 to 4·5 p.p.m. of selenium in their dry matter; the higher figure is considered potentially dangerous to the existence of livestock fed on them.

Three salts, monocalcium phosphate, calcium sulphate, and barium chloride, were added to the soils to determine their inhibitory effect on the uptake of selenium by lucerne.

Selenium absorption by the lucerne was slightly reduced by phosphate in the soil with the lower selenium content (0·5 p.p.m. Se) but was not affected in the soil with the higher selenium content (4·0 p.p.m. Se).

Calcium sulphate proved to be much more effective. It reduced the selenium content of the plants by 60–90 per cent.; the sulphur content of the plants increased. The quantities of gypsum required to produce this effect were very large.

Barium chloride appeared to be the best corrective inhibitory amendment. Apparently it acts by fixing the selenium of the soil in the form of barium-selenium complexes, not readily available to the plant. Small quantities of barium chloride were sufficient to reduce the selenium uptake by plants by 90–100 per cent.

No barium was detected in the plants grown on soils to which barium chloride was added.

IT was found in a previous investigation [1] that forage plants grown on seleniferous soils absorbed excessive quantities of selenium and have endangered the existence of livestock fed on these plants. Selenium concentrations higher than 5 p.p.m. in the dry matter of the forage plants are considered to be potentially dangerous to the life of domestic animals; to cows they may even be fatal [2].

Available information on the relation of plant family to the absorption of selenium by vegetation leads to the conclusion that legumes absorb more than cereals. It is generally claimed that the former absorb twice as much selenium as the latter [3].

Seleniferous soils may be rendered useful for crops either by interfering with the uptake of selenium by the plant, or by preventing the seleniferous soil from releasing its selenium to the plant. This could be based either upon the principles of ion antagonism, whereby the addition of a suitable ion to the seleniferous soil would inhibit the uptake of selenium by the plant; or upon fixing the available selenium in the soil in an insoluble form.

The principle of sulphur-selenium antagonism has been applied by

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various investigators. Some found this method ineffective [4, 5, 6], but the majority present evidence of a definite interference [7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18]. Stress is placed on the different sulphur-selenium ratios that determine the rate of their absorption by the plant during the course of the competitive interference.

No reference was found in the literature to the alternative method of prevention—that of fixing the selenium in the soil.

The purpose of this investigation was to clarify the possibilities of exploiting seleniferous soils in Israel and rendering them useful for growing forage plants free from excessive selenium by either of the two above-mentioned methods.

Three different amendments were used for this purpose: monocalcium phosphate, calcium sulphate, and barium chloride. The phosphate was used to ascertain its influence on the selenium uptake by the plant; calcium sulphate was tried with the purpose of clarifying the extent of its inhibitory action in the local alluvial seleniferous soils. The addition of barium chloride deserves special attention and interest. The reason for using this salt was to fix the selenium in an insoluble form and thus inhibit its release from the soil to the plant.

Materials and Methods

A quadruplicate randomized greenhouse experiment was set up to study the absorption of selenium by plants from two soils containing 0·5 and 4·0 p.p.m. selenium. The control consisted of a soil containing no selenium.

The soils were collected from seleniferous areas on which lucerne was grown. The lucerne grown on these soils was shown to contain toxic quantities of selenium and had endangered the existence of livestock fed on it [1]. The soils were calcareous alluvial silty clays and loams of medium alkaline reaction with appreciable organic matter content. They were fertile and produced good yields of various forage crops. Details of the individual soils are listed in Table 1.

TABLE 1. *Properties of Soils used in Experiments*

Soil no.	*Mechanical analyses* %				*Organic matter* %	$CaCO_3$ %	Se *p.p.m.*	SO_4 *p.p.m.*	*pH*
	Clay	*Silt*	*Fine sand*	*Coarse sand*					
1	41·3	41·9	13·7	3·1	3·15	29·4	none	30	7·8
2	39·3	40·8	16·6	3·3	3·03	33·3	0·5	33	7·7
3	25·5	32·2	37·9	4·4	2·20	33·9	4·0	31	7·7

Asphalt-coated iron pots were used. Each pot was filled with 7·5 kg. of soil. The plant nutrients, nitrogen, phosphorus, and potassium, were added to the soil at rates equivalent to 6 kg. N, 10 kg. P_2O_5, and 9·5 kg. K_2O per dunam[1] in the form of potassium chloride and mono-ammonium phosphate. The salts used as amendments, and the quantities added per pot and expressed on the basis of kg. per dunam, are shown in Table 2.

[1] 1 dunam = ¼ acre.

Lucerne (*Medicago sativa*) was seeded as the test crop. This plant was advisedly selected for its importance as an extensively used forage crop and for its known ability to absorb selenium [1].

The soils were watered to pot capacity every 3–4 days.

TABLE 2. *Treatment of Soils under Investigation*

Treatment no.	*Kind of treatment*	*Soils No. 1, 2, 3*	
		gm. per pot	*kg. per dunam*
1	none	..	..
2	$Ca(H_2PO_4)_2$	3·75	120
3	$CaSO_4$ (1)	18	575
4	$CaSO_4$ (3)	54	1,725
5	$BaCl_2$ (1)	0·25	8
6	$BaCl_2$ (2)	0·50	16

Seven successive cuttings of lucerne were made, one every 5–6 weeks. Samples from the first and fifth cuttings were analysed for their selenium content by the method outlined by Klein [15]; their SO_4 and barium contents were also determined.

Data of yields and contents of Se, SO_4, and Ba in the plants are averages of separate determinations from four pots.

Results

Yields

The development of lucerne on all soils was satisfactory, especially on soil No. 3, a soil of a lighter texture, although containing the largest quantity of selenium. Yields from all three soils with all treatments are presented in Table 3. Different treatments on the same soil resulted in some yield variations. The amendments used somewhat reduced the yields; yield reduction was smallest in soil No. 3.

TABLE 3. *Effect of Treatments on Lucerne Yields*

(*gm. dry matter per pot from seven cuttings*)

Treatment no.	*Kind of treatment*	*Soils*		
		No Se	*0·5 p.p.m.* Se	*4·0 p.p.m.* Se
1	none	75·9	98·2	115·8
2	$Ca(H_2PO_4)_2$	82·4	89·8	109·2
3	$CaSO_4$(1)	82·1	82·3	107·2
4	$CaSO_4$(3)	68·5	88·3	102·1
5	$BaCl_2$(1)	75·2	91·2	109·1
6	$BaCl_2$(2)	66·4	89·1	109·0

Selenium uptake by plant

The influence of monocalcium phosphate, calcium sulphate, and barium chloride on the absorption of selenium by lucerne from the seleniferous soils varied greatly. The supply of 3·75 gm. monocalcium phosphate per pot, equivalent to 120 kg. per dunam, reduced the selenium uptake by the plant from the soil containing 0·5 p.p.m. Se by

approximately 25 per cent. (Table 4). The same quantity of amendment added to the soil containing 4·0 p.p.m. selenium had no such influence; lucerne grown on this treated soil contained a similar amount of selenium to that in the plants grown on the same soil without the addition of phosphate.

TABLE 4. *Absorption of Selenium by Lucerne from Soils treated with* $Ca(H_2PO_4)_2$, $CaSO_4$, *and* $BaCl_2$

(Se *in dry matter of plants—p.p.m.*)

Soil no.	Se *in soil (p.p.m.)*	*Cutting no.*	*Treatments*					
			No treatment	$Ca(H_2PO_4)_2$	$CaSO_4$(1)	$CaSO_4$(3)	$BaCl_2$(1)	$BaCl_2$(2)
2	0·5	1st	1·9	1·4	0·8	0·2	0·3	0
3	4·0	1st	4·6	4·4	1·4	0·9	0·3	0·4
2	0·5	5th	1·6	1·2	0·4	0·2	0·2	0
3	4·0	5th	3·9	4·2	1·1	0·8	0·4	0·4

Least Significant Difference, at P = 0·05, for soil No. 2 — 0·35.
Least Significant Difference, at P = 0·05, for soil No. 3 — 0·28.

The gypsum treatment markedly affected the uptake of selenium by the plant. An addition of 18 gm. calcium sulphate per pot, equivalent to 575 kg. per dunam, greatly reduced the selenium absorption from the soil containing 4·0 p.p.m. Se by more than 70 per cent. With three times as much gypsum, the selenium uptake was reduced still further by 80 per cent.

In the soil containing only 0·5 p.p.m. Se the selenium content of the lucerne grown on it was 0·8 or 0·4 p.p.m. in the first or fifth cuts, when 18 gm. gypsum per pot had been added, and 0·2 in plants supplied with the treble dressing, whereas in the plants from the untreated soils the amounts of Se were 1·9 and 1·6 p.p.m. respectively.

More positive results were obtained by the addition of barium chloride. The smaller quantity of salt added—0·25 gm. per pot, equivalent to 8 kg. per dunam—was assumed to be sufficient to convert the greater part of the available selenium and sulphates present in the soil (Table 1) into a sparingly soluble form. The double dressing of barium chloride was used with the purpose of assuring more effective fixation. It was found that even the smaller quantity significantly inhibited the selenium uptake by the plant. The selenium content of the plants grown in soil with 4·0 p.p.m. Se was reduced by 90 per cent. or more. The double dressing of barium chloride did not further reduce the amount of selenium in the plant.

For soil with only 0·5 p.p.m. Se, the smaller dressing of barium chloride very significantly reduced the selenium content of the plant, from 1·6 or 1·9 to 0·2 or 0·3 p.p.m. respectively. The double dressing completely prevented the uptake of selenium by the plant.

Barium was not detected in the plants grown on these calcareous soils, whether treated with either the smaller or the double dressing of barium chloride. The calcium ion may play a part in inhibiting the barium uptake by the plant [19]. No water-soluble barium was found in the soils treated with barium chloride, at the completion of the experiment.

Sulphur and Selenium in the Plants

The addition of calcium sulphate significantly increased the sulphur content of the plants grown on treated soil.

The ratio of sulphur in the plants grown on gypsum-treated soils to that in those grown on non-treated soils was within the limits of 1·3–2·2; the smaller ratio is represented mostly by plants grown on soils treated with the treble dressing of gypsum. The ratio of S/Se in the plants increased with increased additions of gypsum (Table 5).

TABLE 5. *Sulphur and Selenium in Plants from Untreated and Gypsum-treated soils*

Soil no.	Se *in soil, p.p.m.*	*Cutting no.*	Se *and* S, *p.p.m.*								
			No treatment			$CaSO_4$ (1)			$CaSO_4$ (3)		
			Se	S	S/Se	Se	S	S/Se	Se	S	S/Se
1	None	First	none	267	..	none	483	..	none	473	..
2	0·5	,,	1·9	277	146	0·8	413	516	0·2	347	1,735
3	4·0	,,	4·5	240	53	1·4	417	298	0·9	350	833
1	None	Fifth	none	240	..	none	420	..	none	520	..
2	0·5	,,	1·6	320	200	0·4	427	1,067	0·2	347	1,735
3	4·0	,,	3·9	330	85	1·1	427	388	0·8	373	466

Discussion

The existence in Israel of seleniferous soils producing forage plants of high selenium content has raised the problem of reclaiming these soils by preventing the excessive selenium uptake by the plants.

It was suggested that the solution to the problem could possibly be found in two ways: (*a*) to grow varieties less capable of absorbing selenium or by feeding the animal with more mature plants in which the selenium content is lower [1]; or (*b*) by corrective soil treatments based on the principles of ion antagonism, or fixation of the selenium in an insoluble form.

A previous investigation [1] revealed that most forage plants found in the seleniferous area took up selenium in quantities potentially dangerous to the animals grazing or fed on them; very few plants of agricultural value showed a limited capability of selenium absorption. Lucerne, the main forage plant, proved to have a high capacity for absorption of selenium, its selenium content decreasing with age. Using more mature lucerne for fodder needs cannot, however, solve the problem; such practice would involve a loss of many earlier cuts which are rich in selenium and not suitable as feed for animals. A more practical way of solving the problem is to reclaim the soil by corrective amendments that can impede the absorption of selenium by the plant or prevent its release to the plant from the soil.

Increased quantities of monocalcium phosphate proved ineffectual.

The addition of sulphate in the form of gypsum to counteract the selenium absorption by the plants had been suggested by various investigators. The extent of the effectiveness of this salt by its competitive sulphate anion is still disputable. By testing gypsum as an antagonistic amendment to the local seleniferous soils, it was found that the salt caused a reduction in the selenium uptake by lucerne to a level not dangerous to livestock. However, heavy dressings of gypsum are required to produce the desired effect.

As a corrective treatment involving the conversion of selenium into an unavailable form, barium chloride was found to be very effective even when used in small quantities. This salt had such a considerable inhibiting effect that it completely stopped the absorption of selenium by the plant, from soils containing smaller quantities of selenium. Barium-selenium complexes, assumed to be formed in the soil by this treatment, appear to be of a very sparingly soluble nature and of much reduced availability.

The quantities of calcium sulphate were considerably greater than those of barium chloride required to produce the desired effect.

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NOTE ON THE LAYOUT OF MAIZE FIELD TRIALS

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In Nyasaland almost all maize is hand-planted, on ridges 3 feet apart with the plants in 'hills' of three at 3-foot intervals along the ridge. This method was adopted because of its ease of planting and cultivation and because experiments have shown that it incurs no significant loss in yield as compared with other spacings. It was also the standard practice for maize experiments carried out by the Agronomy and Plant Breeding Sections of the Department of Agriculture, Nyasaland. Plot sizes varied from 2 ridges × 40 hills (240 plants) to 1 ridge × 30 hills (90 plants). This arrangement was particularly unsuitable for the plant-breeding trials, many of which contain large numbers of treatments, thus causing replications to occupy a very large area and making it difficult to fit them into the fields at the Agricultural Research Station, Lilongwe, where the useful size of areas of suitable soil is reduced by the presence of numerous large ant-hills. It was also seen that where three maize plants are grown together in a hill, growth is uneven, very often one or two plants becoming dominant over the rest. Difficulty was also found in establishing perfect stands in large plots.

In an attempt to overcome these difficulties, a trial was grown in 1955–6 with plots of very reduced size, namely, a single ridge with twenty plants spaced singly at 1-foot intervals. This proved so successful that in the 1956–7 season all but one of the plant-breeding trials were of this type. Details of these are given in Table 1 below. These

TABLE 1. *Maize Experiments Established with Single Plants at 1-foot Intervals on the Ridge. All randomized blocks*

Trial	*Size of plot*	*Number of replications*	*Number of treatments*	*Coeff. of variation*
				%
1. Zineb spraying versus non-spraying . . .	1 ridge × 18′ (plants), sub-treatments 4 ridges × 18′, main treatments	6	2 main 4 sub (split plots)	2·95
2. Synthetic varieties . .	1 ridge × 20′ (plants)	6	17	4·3
3. Synthetic, No. 1 selections	1 ridge × 15′ (plants)	6	25	10·6
4. Synthetic, No. 2 selections	1 ridge × 15′ (plants)	6	25	12·4
5. Single crosses . . .	1 ridge × 15′ (plants)	6	125	12·0
6. Top crosses, generations .	1 ridge × 20′ (plants)	6	17	13·0
7. Top crosses . . .	1 ridge × 22′ (plants)	8	49	14·4
8. Rust resisters . . .	1 ridge × 20′ (plants)	6	20	16·4[1]

[1] This experiment was damaged by cattle.

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compare with an average coefficient of variation of 13·3 per cent. for eight previous maize variety trials carried out on this Station.

It is seen that these experiments were of quite satisfactory accuracy and some were extraordinarily so for field trials. It was found that the single maize plants at 1-foot intervals were more easy to establish as a perfect stand and gave much more even growth than three plants in groups at 3-foot intervals. Providing accuracy can be maintained, many advantages are inherent in trials which use small plots, thus:

(*a*) Small size of replications allows them to be fitted into more compact and uniform areas.

(*b*) Small size of each replication allows more replications to be used if necessary, with the area and resources available.

(*c*) With smaller plots, seed requirements are less and thus, especially in plant-breeding work, strains can be included, seed of which is in short supply.

(*d*) Smaller trials can be planted, supplied, cultivated, weeded, and harvested, &c., more easily, and when conditions are most favourable; it has also been found easier to establish a perfect stand on small plots than on large ones. These are all important points in running accurate experiments.

(*e*) The reduced cost of small-size trials means that a greater range of work can be attempted with available resources.

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FIELD STUDIES IN GREEN MANURING. II

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Summary

In continuation of the investigations reported in the previous article [1], experiments were started at Woburn in 1936 to determine the factors which control the efficiency of green manures, and to see how far this is affected by additions of farmyard manure, straw, or a large dose of soluble nitrogenous fertilizer. The effect of several green-manure crops was tested by the growth, after their burial, of a crop of kale or cabbages, followed in the next year by barley. The green manure crops used were (1) vetches or lupins, (2) mustard or rape, both of which were grown in the spring and buried in June or July, and (3) ryegrass or (4) clover, both of which were undersown in the previous crop of barley, and were ploughed into the land in or about June. All were followed almost at once by the sowing of thousand headed kale or, in the later years, by the planting of winter cabbages. In another experiment, farmyard manure, or straw, or a dressing of ammonium sulphate was applied at the time the green manures were buried.

The immediate effect of the green manures was not to any great extent determined by the amount of organic matter buried but there was a remote connexion between the amount of nitrogen in the buried crop and the efficiency of the green manure. The addition of farmyard manure to the green manures did not materially affect the results, but the addition of straw distinctly lowered the yields of the following crop. Addition of large amounts of soluble nitrogenous fertilizer at the time of burial only slightly increased the yields obtained.

The effect of the green manures on the second crop after their burial has been very small, but was a little greater with those green manures with the lower percentage of nitrogen.

The effects of the various green manures on the nitrogen and organic matter status of the soil, after a period of eighteen years, were very similar, but were more marked with those which were undersown in the previous crop of barley.

In the previous part of the present series of studies [1], based on experiments conducted at the Woburn Experimental Station, it was concluded that the manurial value of a green manure, and especially of a highly nitrogenous green manure, depends largely on its being utilized at once before its value has been partially lost either through drainage or from other causes; that its manurial value is not directly connected with the actual amount of nitrogen and still less with the quantity of organic matter buried; that the manurial effect of the burial is very temporary; and that while the two leguminous crops used showed little difference in their value, the use of a non-leguminous crop (mustard) showed very little, if any, advantage.

It was considered worth while to carry the investigations farther, especially as regards the factors determining the efficiency of the green manures, and how far this is affected by additions, at the same time, of farmyard manure, straw, or a large dose of ammonium sulphate. These considerations led to a long-continued experiment in which the effect of a number of green-manure crops was tested by means of a crop of kale or winter cabbages, followed by a crop of barley. The green manure

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crops used were (1) vetches or lupins, (2) mustard or rape, both of which were grown in the spring and buried in June or July, and (3) ryegrass or (4) clover, both of which were undersown in the previous crop of barley, and ploughed into the land in or about June. All were followed almost at once by the sowing of a crop of thousand headed kale or, in the later years, by the planting of a winter cabbage crop. As supplements to the main purpose of the experiment the effect of manuring the kale or the cabbages, in addition, with 10 tons per acre of farmyard manure; or with 30 cwt. per acre of chaffed straw; or with an extra dressing of ammonium sulphate (beyond the basal manuring with ammonium sulphate, superphosphate, and potash given to all plots) was tested.

These experiments were carried on from 1936 to 1954, the first crop for testing the immediate effect of the green manures during the years from 1936 to 1945 being kale and from 1946 to 1953 winter cabbages. Unfortunately, the kale crop in the earlier years failed so often, owing to flea-beetle damage or other causes, that it is impossible to use the figures obtained in those years. But the records for the years when cabbages were grown are complete and are employed in what follows in the present paper.

Very early in the experiments a difficulty arose owing to the fairly frequent periods of drought which prevailed during the later growth of the green manure crops and after their burial, with the result that the land tended to be too dry at the time of burial and thereafter, either for the rotting of the green manures or for the growth of the testing crop. It was clearly necessary to separate the results in the years when this occurred from those when conditions were favourable and when the testing crop could grow normally. The amounts of rain received in the key months of May and June (for the rotting of the green manures) and in July and August (for the growth of the testing crop) for each of the years of the experiment are shown in Table 1.

TABLE 1. *Rainfall in May, June, July, August, for 1946–53 incl.*

Years	*Rainfall, in.*			*Date of burial of green manure crop*
	May and June	*July and August*	*Total 4 months*	
1946	5·64	5·32	10·96	18 June
1947	*2·47*	*1·19*	*3·66*	28 June
1948	6·29	6·67	12·96	30 June
1949	*2·88*	*2·62*	*4·50*	19 July
1950	6·19	7·93	14·12	24 May
1951	3·24	5·53	8·77	8 June or 10 July
1952	3·65	3·57	7·22	13 May or 23 June
1953	3·56	6·08	9·64	4 June or 13 June

The years shown above in italics, namely 1947 and 1949, have been considered separately from the rest, and the main results for the yields of cabbages and of the following crop of barley, for these years, as compared with those for the years when the rainfall was more adequate, are shown in Table 2.

When the rainfall was low and the conditions for the rotting of the

TABLE 2. *Cabbage and Barley Crops after Green Manures, Means for Years of High and Low Summer Rainfall*

Green manures	High rainfall, May to August, years 1946, '48, '50, '51, '52, '53 — Mean yield				Low rainfall, May to August, years 1947 and 1949 — Mean yield			
	Cabbages		Barley		Cabbages		Barley	
	tons per acre	% of fallow	cwt. per acre	% of fallow	tons per acre	% of fallow	cwt. per acre	% of fallow
Fallow .	6·04	..	19·0	..	4·89	..	22·7	..
Clover .	7·86	122	20·7	109	2·52	52	20·0	88
Lupins .	6·52	108	21·0	111	4·00	82	22·5	99
Ryegrass .	5·40	89	19·9	105	2·86	58	20·1	89
Rape . .	5·17	86	20·3	107	2·75	56	20·6	91

green manure consequently unfavourable, the cabbage crop immediately following the burial of the green manure was a good deal less in all cases than that without any green manure at all. When the rainfall was sufficient to allow rapid rotting, there was usually a better test of the potential effectiveness of the green manures. Taking all the green manures used, together, the yield of cabbages, while little affected by the green manures if conditions for rotting were favourable, was reduced by 38 per cent. when the soil was too dry. The second crop (barley) showed relatively less effect, though the reduction in the crop obtained after the green manures in the dry seasons still persisted somewhat. It seems essential, if the real possibilities of the green manures are to be judged, to limit the records to those years when proper and immediate rotting can occur, and hence, in the rest of this paper, consideration is given only to the results obtained in those years when such rotting could easily take place.

In all cases the amounts of organic matter and nitrogen added in the green manures were estimated by sampling the whole of the green manure to be buried, including the roots. These amounts are recorded in the following Table 3. This also shows the mean percentage of nitrogen in the total dry matter of the green manures, together with the yields of the following crops.

TABLE 3. *Weights, Nitrogen Content of Organic Matter buried, and Yields of following Crops*

Green manures	Organic material buried, per acre		Nitrogen in dry matter of green manures	Yield of crops, per acre	
	Total	Nitrogen		Cabbages	Barley
	cwt.	lb.	%	tons	cwt.
Fallow .	36·8	75	1·82	6·04	19·0
Clover .	89·0	212	2·34	7·86	20·7
Lupins .	60·7	160	3·26	6·52	21·0
Ryegrass .	106·8	148	0·90	5·40	19·9
Rape .	67·0	136	1·67	5·17	20·3

From these figures it is clear that the burial of rape, and of ryegrass, has lowered the yield of cabbages. The superiority of the leguminous

crops is very evident. The amount of residual value as tested by the second crop (barley) was small; the most noticeable residual effect was shown by lupins. This agrees with the results given in Part I of this paper which indicated how very temporary was the effect of the burial of even such a nitrogen-rich material as lupin plants.

The above figures also allow the consideration of the question of how far the manurial effect of each of the green manures was determined either by the amount of organic matter buried, by the total amount of nitrogen buried, or by the percentage of nitrogen in that material. The increases in yield of the first and second crops after the green manures were buried, per 100 lb. of organic matter or per 1 lb. of nitrogen contained in the material applied, are shown in Table 4.

TABLE 4. *Relation of Increases in Yield of Crops following Green Manures, to Amounts of Organic Matter and Nitrogen buried (Means for the years 1946, '48, '50, '51, '52, '53)*

Green manures	*Yield increase of cabbages*		*Yield increase of barley*	
	per 100 lb. organic matter buried	*per 1 lb. nitrogen buried*	*per 100 lb. organic matter buried*	*per 1 lb. nitrogen buried*
	lb.	*lb.*	*lb.*	*lb.*
Clover . .	493	224	3·3	1·4
Lupins . .	381	134	8·3	2·6
Ryegrass . .	−179	−1,949	1·4	1·5
Rape . .	−582	−314	4·3	2·4

Thus for the extra organic matter buried in the ryegrass and rape plots there has been a reduction in the yield of cabbages: the opposite is the case with the leguminous green manures. It seems clear that the amount of organic matter, as such, has had little or no influence on the yield of this crop. On the other hand, in all cases there was a small residual value (in terms of added organic matter) as determined by the following barley crop. The nitrogen added in the ryegrass and rape plots has been quite ineffective in increasing the yield of cabbages while, again, the leguminous crops have shown a substantial increase per unit of nitrogen added. In the following crop of barley there has been a slight increase in yield (per unit of nitrogen added) in all cases.

These figures suggest that the amount of organic material buried as green manures has little or nothing to do with the resulting yield of cabbages. On the other hand, there appears to be some, though a remote connexion between the amount of nitrogen buried and the yield of cabbages, but, even in this case, the percentage composition of the material buried seems to be an even more important factor in its effect. As regards the residual value of the material buried, judged by the following barley crop, it would appear as if, on the whole, the material with the lower percentage of nitrogen shows about the same residual effect (per unit of nitrogen) as that with the higher percentage, while in terms of the amount of organic matter added its residual effect was less.

Effect of Addition of other Organic Material to Green Manures on their Efficiency

The whole organic matter content of the green manures forms only a small proportion of that already contained in the soil. If, however, the organic matter so added be augmented by the addition of substantial quantities of farmyard manure or of straw or of both, it is interesting to ascertain whether these further additions modify materially the effect of the green manures themselves. The following paragraphs consider this question.

Farmyard manure. The farmyard manure used in these experiments contained on the average, in the dry matter, 2·52 per cent. nitrogen. As applied, it contained 23·2 per cent. dry matter, and was added at the rate of 10 tons per acre, at the same time as the green manures were buried. The results are shown in Table 5.

TABLE 5. *Effect of Addition of Farmyard Manure to Green Manures, on Yield of following Crops (Means for years 1946, '48, '50, '51, '52, '53)*

Green manures	Green manures with dung				Green manures without dung			
	Organic matter buried	Nitrogen buried	Yield		Organic matter buried	Nitrogen buried	Yield	
			Cabbages	Barley			Cabbages	Barley
	cwt./acre	lb./acre	tons/acre	cwt./acre	cwt./acre	lb./acre	tons/acre	cwt./acre
Fallow	55·8	147·4	6·3	21·5	23·4	9·8	4·7	18·5
Clover	136·5	205·3	8·1	22·2	62·7	137·8	6·4	20·5
Lupins	85·6	236·8	6·8	22·4	34·1	86·4	5·3	21·6
Ryegrass	118·9	294·1	5·6	21·9	81·2	76·0	4·1	19·6
Rape	94·0	203·2	5·4	22·8	40·2	59·7	4·0	19·7

From these figures it would appear that, on the whole, the addition of a fairly large dressing of farmyard manure has made remarkably little difference to the effect of the green manures on the following crops. These differences are shown in Table 6.

TABLE 6. *Increases in Yield of Cabbages and Barley after Green Manures with and without Farmyard Manure*

Green manures	Cabbages		Barley	
	with dung	without dung	with dung	without dung
	tons	tons	cwt.	cwt.
Clover	1·8	1·7	0·7	2·0
Lupins	0·5	0·6	0·9	3·1
Ryegrass	−0·7	−0·6	0·4	1·1
Rape	−0·9	−0·7	1·3	1·2

In general, where there has been any marked difference (namely, with the second—barley—crop), the green manures (except rape) have given higher yields in the absence than in the presence of farmyard manure.

Straw. The chaffed straw used in these experiments contained, in

the dry matter, 0·64 per cent. nitrogen. The influence of the application of 30 cwt. straw per acre of this material is shown in Table 7.

TABLE 7. *Effect of Addition of Straw to Green Manures, on Yield of following Crops (years 1946, '48, '50, '51, '52, '53)*

Green manures	Green manures with straw				Green manures without straw			
	Organic matter buried	Nitrogen buried	Yield		Organic matter buried	Nitrogen buried	Yield	
			Cabbages	Barley			Cabbages	Barley
	cwt./acre	lb./acre	tons/acre	cwt./acre	cwt./acre	lb./acre	tons/acre	cwt./acre
Fallow .	50·3	86·0	6·13	20·2	23·8	68	5·73	19·8
Clover .	100·7	224·7	7·75	20·9	74·3	199	7·73	21·3
Lupins .	74·8	177·2	6·33	22·3	46·5	151	6·88	21·6
Ryegrass .	116·7	156·2	5·17	21·3	94·4	139	5·34	20·2
Rape .	81·6	144·7	4·74	20·9	55·0	129	5·53	21·7

The addition of straw to the green manures has, on the whole, reduced their value as manures, as is shown in Table 8.

TABLE 8. *Increases in Yield of Cabbages and Barley after Green Manures with and without Straw*

Green manures	Cabbages		Barley	
	with straw	without straw	with straw	without straw
	tons/acre	tons/acre	cwt./acre	cwt./acre
Clover . .	1·62	2·00	0·7	1·5
Lupins . .	0·20	1·15	2·1	1·8
Ryegrass . .	−0·96	−0·39	1·1	0·4
Rape . .	−1·39	−0·20	0·7	1·9

The results show what would have been expected in view of the well-known fact that organic materials containing less than about 1·8 to 2·0 per cent. of nitrogen generally cause a lowering in yield of the crops which follow their applications. So far as the first crops after the applications are concerned, the effect of the addition of straw has been injurious in every case, having led to a decrease in the crop of cabbages. This would have an important bearing on the question of ploughing in the straw after a corn crop as against its removal. The second crop (barley) after the burial of the green manures, was not, on the whole, much depressed by the addition of the straw in the previous year.

Effect of Additions of Nitrogenous Fertilizers to Green Manures on their Efficiency

It has usually been stated that, as the burial of materials containing a low percentage of nitrogen leads to a reduction in the yield of the immediately following crop, it is probable that if this low percentage is supplemented by the simultaneous application of a nitrogenous fertilizer, the organic materials added may then prove as useful as if they themselves contained a higher percentage. Consequently, in the present

series of experiments, a comparison has been made of crops resulting, with each green manure, from doubling the amount of such nitrogenous fertilizer as would normally be given at the same time as the green manure was buried. The normal dressing of ammonium sulphate was 2 cwt. per acre, the double dressing being 4 cwt. per acre. The yields of the first (cabbages) and the second (barley) crops after these additions are shown in Table 9.

TABLE 9. *Effect of Increased Dressings of Ammonium Sulphate with Green Manures, on Yield of following Crops (years 1946, '48, '50, '51, '52, '53)*

Green manures	Green manures with 2 cwt. ammonium sulphate per acre				Green manures with 4 cwt. ammonium sulphate per acre			
	Organic matter buried	Nitrogen buried (as green manures)	Yield		Organic matter buried	Nitrogen buried (as green manures)	Yield	
			Cabbages	Barley			Cabbages	Barley
	cwt./acre	lb./acre	tons/acre	cwt./acre	cwt./acre	lb./acre	tons/acre	cwt./acre
Fallow	36·8	77	5·08	19·0	36·8	77	5·99	18·0
Clover	95·5	228	6·75	18·6	86·4	201	8·00	20·2
Lupins	59·1	158	5·48	20·2	60·5	162	6·92	20·8
Ryegrass	111·6	149	4·20	18·2	106·0	144	5·44	20·0
Rape	63·5	127	4·39	20·0	69·8	129	5·47	19·6

Table 10 shows the increase in yield resulting from each of the green manures as affected by the presence of the additional amount of ammonium sulphate.

TABLE 10. *Increases in Yield of Cabbages and Barley, from Green Manures along with Single and Double Dressings of Ammonium Sulphate*

Green manures	Cabbages		Barley	
	with 2 cwt. ammonium sulphate	with 4 cwt. ammonium sulphate	with 2 cwt. ammonium sulphate	with 4 cwt. ammonium sulphate
	tons/acre	tons/acre	cwt./acre	cwt./acre
Clover	1·67	2·01	−0·4	2·2
Lupins	0·40	0·93	1·2	2·8
Ryegrass	−0·88	−0·55	−0·8	2·0
Rape	−0·69	−0·52	1·0	1·6

These figures show that for the cabbage crop the additional quantity of nitrogenous fertilizer has tended to cause larger crop increases with green manures. This applies even more to the second crop (barley). On the whole, however, the effect of the additional amount of nitrogenous fertilizer has been surprisingly small.

Effect of long-continued Green Manuring on the Soil

The long-continued green manuring, with or without the addition of farmyard manure or straw, has made a substantial addition to the organic

and nitrogen status of the soil. The relative effect of the various green manures in increasing the nitrogen and organic matter resources of the soil is shown in Table 11.

TABLE 11. *Effect of Eighteen Years Green Manuring on Nitrogen and Organic Matter Content of the Soil*

	Nitrogen			*Organic matter*		
	1936	*1954*	*% increase*	*1936*	*1954*	*% increase*
	%	%		%	%	
No green manure .	0·090	0·102	13	1·49	1·74	17
Mustard or rape .	0·091	0·105	15	1·49	1·86	25
Tares or lupins .	0·089	0·106	19	1·47	1·81	23
Clover and ryegrass alternately . .	0·091	0·115	22	1·47	2·03	39

These figures have no absolute value as they contain in each case the plots which were also treated with farmyard manure or straw, but they are strictly comparable and show what a slight difference in the final status of the soil has been made by the addition of the green manures except in the case of the clover and ryegrass plots, which were, of course, sown in the previous crop of barley. In these cases the increase in both the nitrogen and the organic matter is higher than in any other case. The organic matter was determined by the method of Walkley and Black.

The effect of adding 180 tons of farmyard manure or 27 tons of straw per acre to the land during a period of eighteen years is shown in Table 12.

TABLE 12. *Effect of Supplementing Green Manures with Farmyard Manure or Straw, on the Nitrogen and Organic Matter Content of the Soil*

		Farmyard manure		*Straw*	
		Nitrogen	*Organic matter*	*Nitrogen*	*Organic matter*
		%	%	%	%
1936	Original values . . .	0·091	1·49	0·091	1·47
1954	Plots with additions . .	0·115	2·07	0·110	1·96
	Plots without additions .	0·099	1·70	0·106	1·81
	% Increase due to additions.	17·5	21·6	3·8	9·4

Conclusions

On the whole, the benefit derived from the green manures is disappointing, but, whatever it is, it is certain that it is determined by a combination of several causes and not exclusively by one of the variables in the experiments.

The following conclusions are drawn:

1. It is quite clear that the immediate effect of the green manures has not been determined to any great extent by the actual amount of organic material buried.

2. There appears to be some, though a remote, connexion between the amount of nitrogen buried and the yield of the immediately following crop (cabbages). But the percentage composition of the material buried is a more important factor in the value of the green manures. This effect will be dealt with in more detail in a paper now under preparation.

3. The addition of farmyard manure to the green manures at the time of their burial has not materially affected the immediate benefits obtained.

4. The addition of straw to the green manures, in about the amount which would be buried if the whole of the straw furnished by a normal grain crop were buried, in all cases distinctly lowered the yields of the immediately following crop.

5. The addition of a large amount of soluble nitrogenous fertilizer to the green manures at the time of burial has somewhat increased the immediate benefits obtained.

6. The effect of the green manures on the second crop (barley) after they were buried was very small, but was a little greater with those green manures with the lower percentage of nitrogen.

7. The effects of the various green manures on the nitrogen and organic matter status of the soil, after a period of eighteen years, have been very similar, but were more marked with those green manures which have been undersown in the previous crop of barley.

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BUFFALO KEEPING IN BARNS, AND MECHANICAL MILKING IN THE SALERNO DISTRICT

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WITH PLATES 5, 6, 7

Summary

The present and future status of the buffalo as a commercial dairy animal in Italy is discussed. The methods successfully adopted for keeping milking buffaloes in barns along with ordinary dairy cows are described, and data for milk production of three herds in the Salerno district are presented. In one of these herds the buffaloes are milked mechanically.

Although buffaloes produce only about half as much milk as ordinary cows under comparable conditions, its butterfat content is about twice as high. The buffalo is thus able to compete economically with ordinary dairy cattle under conditions where its special characteristics of relative freedom from disease, and ability to make better use of coarser and cheaper fodder, are of first importance, and having regard to the increasing demand for the special types of cheese (e.g. 'Mozzarella') made from it.

Buffalo Keeping in Modern Times

THE keeping of buffaloes in Italy, particularly during the last twenty years, has been diminishing, as more and more land has been drained and improved, and thus rendered fertile, in the Lazio province (Pontine Marshes), in the Campania province (Piana del Volturno), in the Caserta district and Piana del Sole, and in the Salerno district. In all these regions buffaloes used to be numerous, and they greatly helped to provide food (milk, meat), as well as labour for the local inhabitants. Milk production was always most appreciated, particularly in connexion with the production of the well-known local soft cheeses ('Mozzarella', 'Provolone', and 'Uovo di Bufala').

Early in 1800 the buffaloes in Italy comprised some 60,000 head. In 1876–81 the approximate number was 11,000; in 1909, 19,000; in 1918, 24,000; in 1930, 15,000; and in 1939, 12,000. At present the total number is thought to be 5,000 or 6,000.

In the Lazio province only a few hundred buffaloes can now be found, and a few hundred more at 'Piana del Volturno'. A larger number, still not exceeding a few thousands, can be found in the Salerno district, on either side of Sole. Some thousand head are scattered in the provinces of Puglie and Lucania.

Agricultural and health conditions have steadily changed almost everywhere. Great hydraulic and agrarian improvements have been carried out. Up-to-date highly productive farms are now thriving where only some twenty-five or thirty years ago there were marshes, thickets, and malaria. The land improvement already achieved has established the safety of a large number of small rural properties, the life of which is closely linked up with the highest agricultural and zootechnical exploitation, and where, therefore, buffalo keeping cannot any longer be taken into consideration.

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The presence of buffaloes, therefore, might even appear to be an anachronism, and their now somewhat increasing numbers, particularly in the Battipaglia district, might be considered as a return to a past in which their presence was a token of poverty and backwardness.

Those in charge of agricultural and zootechnical control are not all in favour of the buffalo breed. However, the number of breeders who favour it is increasing because of contingent economic reasons. The circumstances of the people concerned must therefore be taken into account in deciding whether such increase is justified. The economic reasons behind the present tendency to continue and even slightly increase the keeping of buffaloes, apply only in certain contingencies, but they do not seem to be such as to bring about a general preference for buffaloes over cattle.

The higher price fetched by buffalo milk as compared with cow's milk is one of the chief economic factors. Whilst the former is being sold at Lires 100 to 105 per kilo, cow's milk is quoted at only Lires 40 to 50 per kilo. The 'Mozzarella' cheese is not only in great local demand, but it is also increasingly exported throughout Italy including the northern districts. This cheese is being more and more consumed both as such and for the preparation of traditional southern dishes that have now become popular all over the country. One of them is the well-known 'Pizza' hardly to be found in the north before the war, and now sold everywhere.

Another factor that explains why, in some circumstances, buffaloes may be preferred lies in the lower cost of maintenance and production, deriving from general and feeding expenses, inasmuch as buffaloes are able to make better use of fodder and cheaper foods as compared with cattle, particularly when the latter belong to dairy breeds such as the Friesian and the Brown Swiss. Very often fodder left over by cattle is fed to buffaloes, and it is, therefore, clear that milk and meat from these animals can be obtained at a lower cost.

The amount of milk produced by the buffalo is, on the average, less than that produced by the cow. The milk yield of a single buffalo is about 15 to 20 quintals[1] per annum. However, females producing over 20 quintals, sometimes up to 25–30 quintals of milk per lactation, are becoming more and more numerous. An average milk yield of 20 quintals at the third lactation is regarded as satisfactory.

The milk of buffaloes contains from 6 to 8 per cent. or even more butter fat, and it fetches a price nearly twice that of ordinary cow's milk; the cost of keeping buffaloes is 20–30 per cent. less than that of cattle; under similar conditions, buffalo females use some 20 per cent. less fodder than ordinary cows; from 18 to 24 per cent. more fresh cheese can be made from buffalo milk.

An ordinary cow with a milk yield of 40 quintals in the lactation, sold at Lires 5,000 per quintal, gives a gross return of Lires 200,000. A buffalo producing only 20 quintals of milk which, however, can be sold at Lires 10,000 per quintal will give the same gross return, but the purchase and keeping costs are less. In fact, when considering the expenses

[1] One quintal = 100 kilogrammes = 220·5 lb.

of keeping and feeding cattle, the loss caused by genital diseases, &c., the cost of ordinary cow's milk will exceed that of buffalo milk by 20 to 30 per cent. Actually the advantage may even be higher since buffaloes are very sturdy, and free from most infectious and common diseases that affect cattle. The buffalo specific pathology, in fact, is restricted to Specific Pasteurellosis and very few other ailments. Buffaloes are very seldom affected by genital diseases. On the other hand they grow more slowly than cattle, and they reach sexual maturity later. Buffaloes live longer than cattle, and females bringing forth ten to fourteen calves are quite common. Buffalo females seem to suffer more frequently from vaginal prolapse, which, however, can be easily controlled with a timely treatment of calcium.

Buffalo females have a comparatively longer 'dry' period lasting 5 to 6 months. The impossibility for these animals to be on pasture every day also reduces the total amount of manure produced.

At present buffalo keeping is being carried on mostly in an entirely different way from that prevailing in the past, when very primitive methods were used, such as are still employed in most Mediterranean, African, and Asiatic countries where buffaloes are kept.

Buffaloes used to be kept in a wild condition on marshes, where they lived in the open winter and summer alike. They fed on whatever nature could afford, according to the season of the year. In summer the difficulties would become serious because of the insufficient amount of fodder available, and the heat and dryness, which greatly affect these animals. In the past buffalo herds also used to be dangerous to those not travelling on horseback. Buffalo females followed by bulls could not be approached except with extreme care. Milking was carried out only in the presence of the calf, as it was thought that only under such conditions would the milk flow be released, because of an inhibitory reflex action.[1]

Buffalo Keeping in Barns

The results obtained by an increasing number of farmers, particularly in the Salerno district, confirm the possibility for buffalo females to be reared in barns, under the same conditions as cattle, with which they sometimes even share the same barn (Figs. 1 and 2, Pl. 5). Milking is almost always carried out in the barn. The old prejudices have been overcome, and milking is now carried out by almost any farm hand, and in the absence of the calf without the milk yield being affected.

Buffalo calves retain the characteristics of their species, including great untameness. However, they are becoming more and more used to the presence of men, and only very seldom do they become dangerous.

Buffaloes reared under such conditions cannot, however, be permanently kept in barns (which is also true for cattle). They should be turned out to pasture for a few hours every day, and left in an open enclosure as long as possible (Fig. 3, Pl. 5). Furthermore, buffaloes

[1] The young buffalo is known as a 'calf' up to 5 or 6 months of age; the female during the 'dry' period after weaning is called *assecaticcia*; yearlings are called *cannutolo* or *annutola* or *annecchia*; the female from pregnancy to parturition is known as a 'heifer'.

need a dipping in water every day, or, at least to be sprayed with water several times a day during the hot season not only for cooling reasons, but also to relieve them from parasites (Figs. 4 and 5, Pl. 6). Water, in fact, is a physiological need for the species (as explained by the term 'Water Buffalo'). When no water is available they tend to dig large holes in the ground until layers of wet mud are reached, in which they wallow for hours.

TABLE 1. *Milk Yield of Buffalo Heifers Reared in Barns at the S.A. Bonifiche (Battipaglia), which completed their Lactations in the Year 1956–7*

Number	*Milk yield for lactation (quintals)*	*Duration of the lactation period (days)*
01	12·755	260
03	19·288	335
04	15·851	304
05	14·267	229
06	10·349	230
07	17·275	245
09	19·522	273
010	15·817	289
012	14·793	229
014	15·667	334
015	11·974	212
016	16·117	258
017	12·399	214
018	18·055	289
021	11·679	212
022	15·969	273
024	13·710	258
033	16·039	227
02	21·115	396
08	17·870	304
013	14·680	304
019	20·562	350
032	18·899	273
034	17·426	258
026	26·867	426
020	28·385	502
011	22·652	395
036	10·316	227

Number of buffalo heifers having completed lactation	28
Average milk yield per lactation (quintals)	16·583
Average duration of the lactation period	289 days
Average milk yield per heifer per day	5·738 kg.

Table 1 shows data for the year 1956–7 of buffalo heifers reared in barns on the farm of the S.A. Bonifiche di Battipaglia. The average milk yield per lactation is 16·58 quintals per head, an amount which is certainly significant.

Table 2 shows the equally significant data concerning a herd also reared in barns and belonging to the Farm 'Angelo di Difesa Nuova' at

Pontecagnano (Salerno). Putting the milk yield of the first lactation at 100, it is expected that the yield of the second lactation will be about 140.

Italian buffaloes are certainly high milk producers, and probably the highest producers for this breed in the world. Thus the export of sires might prove profitable in the near future. Countries likely to be interested in importing these sires could be in the Mediterranean area or elsewhere where buffaloes are being bred.

A rational plan of improvement for buffaloes has never been carried out as is done with cattle (control of diseases, progeny test of sires, breeding control (inbreeding only to the necessary extent), family and inter-breed selection, &c.).

By using such methods satisfactory results might be expected provided reasonable care is taken to avoid reducing the other useful characteristics of this species, such as will help to make profitable the rearing of buffaloes under various local conditions (sturdiness, frugality, high power of food assimilation and conversion, &c.). Experts believe that Italian buffaloes show morpho-functional differences of such prominence as to suggest that they are racial or sub-racial characteristics. However, it is more probable that such differences are merely restricted to a different frequency in gene determination, as they occur in herds that have been marooned in a given area for years and even centuries, thus developing some different phenotypical characteristics in the genetic-environmental integration, however strictly genotypical.

In 1939 the Ministry of Agriculture and Forests officially established the species standards. The progress of genetic studies and the rules of modern zootechnology afford more suitable facilities, and with easier results, because of the greater fundamental uniformity of the type.

It is sometimes assumed that buffaloes reared in barns produce milk of a lower butterfat content than those left free on pasture, but this has not been confirmed by any reliable experiments. Nor can we rule out that even in such a case some peculiar genotypical conditions might occasionally play a part. Another unreliable and at the same time contradictory statement is that buffaloes with a white head are higher milk producers according to some, and lower milk producers according to others.

Three more questions needing consideration are:

1. Better housing for buffaloes, i.e. sheds where the animals can be placed along two rows facing each other, with a wide passage between for food trucks.

2. The preparation of proper concentrate mixtures for the feeding of buffaloes, since those in use at present are not the most suitable to increase production.

3. The need to find new methods to prolong the use of sires, which are thought to become dangerous after the age of 4 years. The common practice of natural mating should, therefore, be modified, so that the sires mount the cows in special enclosures or crates, reached by passages with strong railings so that herdsmen would be protected. Furthermore, a ring should be fixed in the nose of young buffalo bulls, as it is done with cattle.

TABLE 2. *Milk Yield of Buffaloes in the 'Angelo di Difesa Nuova' Herd at Pontecagnano*

Buffalo			*Calvings*		*Production*		
No.	*Date of birth*	*Name*	*No.*	*Date*	*Days of lactation*	*Kgm. of milk*	*Remarks*
1	June 1942	Come Siervi	4	15/10/48	214	2,012	Dam of Il Governo (No. 18) and Solo a Te (No. 14)
			5	25/9/49	212	2,038	
			6	27/8/50	222	2,060	
			7	1/8/51	234	1,884	
			8	5/8/52	243	2,267	
			9	19/7/53	243	2,317	
			10	27/8/54	51	605	Lactation incomplete
2	Aug. 1942	Battipaglia 1st	4	28/6/48	211	2,154	Sister of BattipagliaII (No. 8). Dam of Nun è Cosa (No. 22)
			5	28/6/49	214	2,100	
			6	4/6/50	254	2,202	
			7	28/7/51	233	2,269	
			8	2/7/52	215	2,028	
			9	14/6/53	235	2,355	
			10	1/6/54	102	1,219	Lactation incomplete
3	Oct. 1943	Caroerata	3	6/12/48	212	2,022	
			4	21/11/49	243	2,346	
			5	27/12/50	263	2,200	
			6	11/6/52	215	2,047	
			7	29/7/53	243	2,096	
			8	23/8/54	20	216	Lactation incomplete
4	10/1/44	Sazia Mai 1st	2	1/6/48	217	1,815	Sister of Sazio Mai II (No. 7). Dam of Ma Te ne Vai (No. 19) and Mai Contenta (No. 21)
			3	10/6/49	214	2,055	
			4	27/5/50	214	2,060	
			5	24/5/51	224	2,123	
			6	28/5/52	234	2,095	
			7	31/5/53	214	2,172	
			8	24/6/54	82	1,053	Lactation incomplete
5	4/8/44	Rispettata	2	15/8/48	328	2,333	
			3	10/10/49	253	2,180	
			4	4/10/50	273	2,200	
			5	16/9/51	264	1,955	
			6	7/9/52	263	2,346	
			7	17/8/53	253	2,111	
			8	7/9/54	..	..	Lactation incomplete
6	21/11/44	La Tredicesima	2	30/7/48	253	2,001	
			3	24/8/49	232	1,971	
			4	2/8/50	284	2,120	
			5	28/8/51	386	3,228	
			6	12/1/53	386	3,333	
			7	20/5/54	112	1,273	Lactation incomplete
7	2/1/45	Sazia Mai II	2	16/10/48	326	2,225	Dam of La Bussola (No. 10)
			3	17/4/50	234	2,013	
			4	6/7/51	184	1,574	
			5	17/6/52	334	2,491	
			6	15/2/54	212	1,854	Lactation incomplete
8	17/12/45	Battipaglia II	1	11/4/48	..	..	Calf slaughtered. Dam of Primula (No. 20)
			2	12/6/49	215	1,704	
			3	3/6/50	245	1,949	
			4	8/7/51	244	1,909	
			5	8/7/52	253	2,237	
			6	2/9/53	222	1,884	
			7	26/8/54	..	..	Lactation incomplete
9	8/11/46	Da Napoli	1	3/9/49	181	1,355	Dam of Il Bugiardo (No. 13), and Statti Allegra (No. 17)
			2	13/8/50	262	2,201	
			3	14/8/51	203	1,681	
			4	25/7/52	253	2,594	
			5	7/5/53	..	..	Calf slaughtered following injury
			6	19/5/54	112	1,417	Lactation incomplete

TABLE 2 (cont.)

Buffalo			*Calvings*		*Production*		
No.	*Date of birth*	*Name*	*No.*	*Date*	*Days of lactation*	*Kgm. of milk*	*Remarks*
10	13/5/47	La Bussola	1	22/5/50	224	1,791	
			2	12/9/51	325	2,128	
			3	9/1/53	233	2,009	
			4	20/12/53	263	2,214	Lactation incomplete
11	31/5/47	Il Guardiano	1	2/8/50	273	1,331	
			2	13/9/51	243	1,689	
			3	24/8/52	273	2,003	
			4	29/9/53	291	2,009	
12	19/9/47	Chi TI Protegge	1	5/9/50	263	1,518	
			2	11/9/51	253	1,721	
			3	16/8/52	223	1,802	
			4	31/7/53	220	2,001	
			5	15/7/54	62	647	Lactation incomplete
13	7/11/47	Il Bugiardo	1	18/6/50	263	1,652	Sister of Da Napoli
			2	26/8/51	253	2,027	(No. 9)
			3	27/8/52	222	2,039	
			4	17/8/53	243	2,288	
			5	22/7/54	51	604	Lactation incomplete
14	12/11/47	Solo a Te	1	14/8/50	223	1,385	Daughter of Come
			2	11/8/51	213	1,546	Siervi (No. 1)
			3	1/8/52	233	1,825	
			4	10/7/53	233	2,029	
			5	14/6/54	92	1,079	Lactation incomplete
15	28/7/48	Il Padrone	1	17/7/51	223	1,611	
			2	3/8/52	253	2,175	
			3	1/9/53	232	2,186	
			4	22/8/54	20	262	Lactation incomplete
16	5/8/48	Armatura	1	2/4/51	214	883	Calf slaughtered
			2	28/5/52	245	1,743	
			3	27/6/53	263	2,173	
			4	15/7/54	62	719	Lactation incomplete
17	12/10/48	Statti Allegra	1	12/7/51	285	1,879	
			2	3/11/52	202	1,937	
			3	30/9/53	212	2,058	
			4	2/9/54	..	..	Lactation incomplete
18	15/8/48	Il Governo	1	11/9/51	233	1,476	
			2	25/8/52	223	1,727	
			3	8/7/53	253	1,869	
			4	27/8/54	51	544	Lactation incomplete
19	10/6/49	Ma Te Ne Vai	1	15/7/52	264	2,112	
			2	27/7/53	202	2,122	
			3	6/8/54	41	502	Lactation incomplete
20	12/6/49	Primula Rossa	1	3/8/52	222	1,490	
			2	26/8/53	233	2,135	
			3	27/9/54	..	..	Lactation incomplete
21	27/5/50	Mai Contenta	1	15/8/53	223	1,489	
			2	8/8/54	41	432	Lactation incomplete
22	4/6/50	Nun è Cosa	1	2/8/53	283	1,562	
			2	24/9/54	..	..	Lactation incomplete

Mechanical Milking of Buffaloes

The Signorini herd at Eboli (Salerno) is probably the only one in Italy, and perhaps abroad, where mechanical milking of buffaloes is carried out. This method has been practised there ever since 1954 with satisfactory results (Figs. 6 and 7, Pl. 7).

This herd consists of thirty-two Friesian cows and thirty-eight local buffaloes. Both species are being reared in the same barn and looked after by the same farm hands (Figs. 1 and 2, Pl. 5).

The Gascoigne milking machine is used, and it is now planned to adopt electronic control, the advantage of which is to allow the simultaneous milking of the four teats.

Buffaloes are fed in the barn on grass, hay, beet pulp (fresh and dried), according to the season of the year. They also receive 1 kg. of a special concentrate mixture containing 19–20 per cent. of digestible protein, which is specially prepared by a local factory. During not less than 7 to 8 months every year buffaloes are chiefly fed on beet pulp and pasture (clover, lucerne, &c.).

Buffalo heifers are submitted to mechanical milking soon after calving, that is at about 30 months of age. They get used to it quickly and easily, just as do older buffaloes including those already used to being milked in the presence of the calf.

The udder is massaged before being submitted to mechanical milking. Nearly all calvings take place in spring. The suckling period of buffalo calves destined for milk production lasts about 3 months; they are then fed suitable mixtures and let out on pasture. Buffaloes are milked twice a day. In pregnant females the 'drying off' period occurs at the seventh month of pregnancy with no ill effect. As a rule a calf due for slaughter is taken away from its dam at the end of the colostral period, viz. 7 to 8 days after birth, and fed entirely on ordinary cow's milk (because this is less expensive) for 1 month.

The buffaloes in the Signorini herd are of ages ranging from 2½ up to 9 or 10 years. Their liveweight is about 650 kg.

The cow-shed is roofed with tiles, and lined with bricks on the inside. The stalls are of the American type, but with a vertical chain fastening instead of the stiff ring fastening (Fig. 2, Pl. 5). Contrary to the local custom, the buffaloes' tails are not docked since the animals with tails can whisk flies off and thus keep quieter.

In summer the buffaloes are sprayed with water within an enclosure (Fig. 4, Pl. 6), and they are left out in the open also during the night. In winter they are turned out to pasture every day.

Table 3 shows data on the production of the buffaloes in this herd. The general average yield was 21·98 quintals. Out of 20 buffaloes 17 have produced 20 quintals or more; ten, 23 quintals or more; seven, 25 quintals or more; and one, 34·01 quintals.

The average lactation period is 308 days, with an average milk yield of 6·6 kg. per head per day.

An analysis of the butterfat content of these buffaloes' milk has given the following results:

Name of the buffalo	*Butterfat content* %
Aprile	6·8
Hong	7·5
Susa	7·1
Giava	7·0
Tahiti	7·2

TABLE 3. *Milk Yield of Buffaloes from the Signorini Herd (Battipaglia) Submitted to Mechanical Milking*

No.	*Year*	*Name*	*Date of birth*	*Date of calving*	*Lactation*	*Total milk yield (two milkings a day) quintals*	*Duration of lactation (days)*	*Milk yield per day kg.*
13	1954	India	1949	6/9/54	3rd	18·09	295	6·1
..	1957	..	..	11/2/57	4th	21·59	304	7·1
8	1955	Celebos	1955	23/11/55	2nd	17·55	262	6·6
..	1957	..	..	5/2/57	3rd	17·78	257	6·9
1	1955	Dora	8/7/52	21/7/55	1st	18·81	325	5·7
..	1957	..	..	13/11/56	2nd	19·30	266	7·2
2	1955	Flora	10/3/52	30/7/55	1st	16·11	295	5·4
..	1955	..	..	19/10/56	2nd	19·44	344	5·6
3	1955	Giava	1949	18/7/55	4th	25·64	318	8·0
..	1956	..	..	30/9/56	5th	22·06	275	8·0
14	1955	Formosa	1951	21/8/55	1st	17·52	305	5·7
..	1957	..	..	20/10/56	2nd	27·20	386	7·0
4	1955	Tahiti	1951	22/8/55	1st	18·45	253	7·6
..	1956	..	..	2/8/56	2nd	22·24	282	7·8
5	1955	Shanghai	1950	25/8/55	2nd	24·80	281	8·8
..	1957	..	..	31/1/57	3rd	21·34	252	8·4
6	1955	Egizia	1951	30/8/55	2nd	19·92	275	7·2
..	1957	..	..	31/10/56	3rd	26·34	345	7·6
15	1955	Marcella	1949	16/9/55	1st	23·07	371	6·2
..	1955	..	..	19/3/57	2nd	14·23	267	5·3
7	1955	Zaira	1951	17/9/55	1st	23·68	288	8·2
9	1955	Araba	1951	25/9/55	1st	15·08	250	6·8
..	1956	..	..	3/9/56	2nd	20·26	338	5·9
10	1955	Fauszia	1951	14/10/55	2nd	17·84	292	6·1
..	1956	..	..	10/10/56	3rd	25·17	356	7·3
11	1955	Superba	1949	15/10/55	2nd	27·02	260	10·6
..	1956	..	..	22/9/56	3rd	34·01	374	9·0
12	1955	Marina	22/7/53	3/11/55	1st	11·09	231	4·8
16	1956	Africa	1951	30/5/56	2nd	28·96	489	5·3
17	1956	Terzilia	1949	11/6/56	2nd	21·25	263	8·0
18	1956	Tea	1953	25/6/56	1st	21·87	407	5·3
19	1956	Gorina	1950	22/7/53	1st	16·99	357	4·7
					Mean	21·80	308	6·6

These figures belie the assertion that rearing in barns affects the butterfat content of buffalo milk.

The milk produced by buffaloes in the Signorini herd is used for the production of 'Mozzarella' cheese.

(*Received 22 May 1958*)

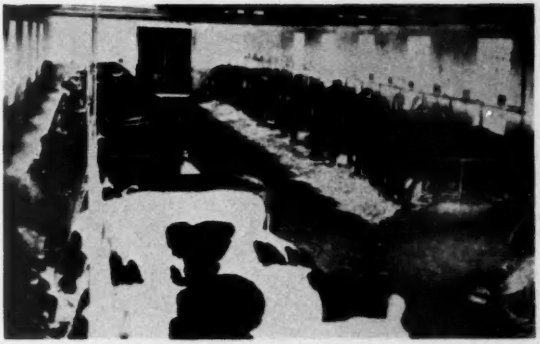

FIG. 1. The Signorini herd at Eboli consisting of ordinary cows and buffalo cows sharing the same barn

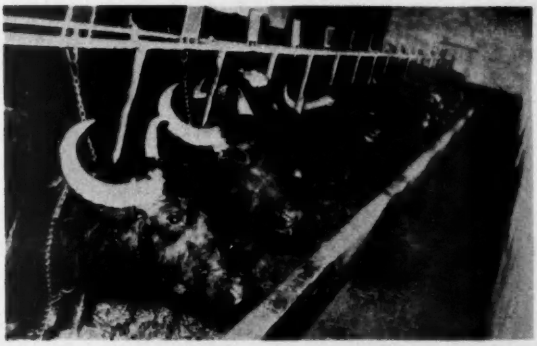

FIG. 2. The Signorini herd at Eboli. Buffalo cows in barns with chain fastening

FIG. 3. The Signorini herd at Eboli. Female buffalo calves and ordinary heifers in the same enclosure in the open air

FIG. 4. Buffaloes from the Signorini herd at Battipaglia receiving their daily spraying with water

FIG. 5. Buffalo cows from 'Piana del Sole' bathing in the river

FIG. 6. A typical udder of a buffalo from the Signorini herd at Battipaglia

FIG. 7. The Signorini herd at Eboli: mechanical milking

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